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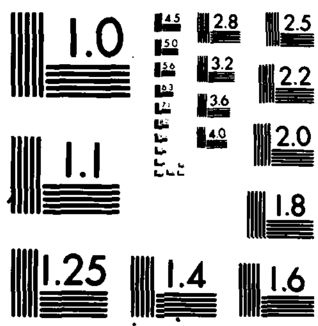

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USAAEFA PROJECT NO. 79-19

LEVEL III

ARTIFICIAL AND NATURAL ICING TESTS PRODUCTION UH-60A HELICOPTER

FINAL REPORT

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A limited evaluation of the production UH-60A Black Hawk anti-ice and deice systems was conducted to determine the capability to operate safely in a moderate icing environment. Artificial and natural icing tests were conducted at St. Paul, Minnesota, from 11 February through 31 March 1980. Testing was performed by the United States Army Aviation Engineering Flight Activity and consisted of 27.1 productive flight hours. During these tests, three deficiencies and fourteen shortcomings were noted. The two icing related deficiencies are: failure of the droop stops to return to the shutdown position after ice accumulation on the main rotor head and failure of the anti-flapping restrainers to return to the shutdown position after ice accumulation on the main rotor

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) head. One non-icing environment related deficiency was the interference between the main rotor blade trailing edge and the ALQ-144 IR countermeasures device with a droop stop in the incorrect shutdown position. The major shortcomings are: large power required increases with ice accumulation on the rotor system, large power available losses with the engine and engine inlet anti-ice systems ON and the poor location of the deice system circuit breakers. Eleven additional shortcomings were identified. The UH-60A, configured with the deice and anti-ice systems tested, demonstrated an excellent potential for operating in an icing environment. Upon correction of the icing related deficiencies the helicopter should have the capacity to operate safely in icing through moderate conditions. Flight in icing conditions does not noticeably change the handling qualities of the helicopter. The range and endurance characteristics of the UH-60A are significantly degraded during flight in icing conditions. The ice detection subsystem indicates icing rates which appear to correlate with accepted icing severity definitions. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.5.1.1.6 of the Prime Item Development Specification, DARCOM-CP-2222-S1000D Part I, in that, the failure of the droop stops and flap restrainers to return to the shutdown position precludes safe operation in a moderate icing environment.

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DRDAV-DI

SUBJECT: Directorate for Development and Qualification Position on the Report of USAAEFA Project No. 79-19, Artificial and Natural Icing Tests, Production UH-60A Helicopter

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1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report. The icing tests were conducted for the purpose of qualifying the production UH-60A helicopter for operation under moderate icing conditions as required by the Material Needs Document. Based on the icing test results, additional icing tests are required prior to field release to evaluate design changes to the droop stops to preclude ice accumulation which results in failure of the droop stops to return to the static position during shut down. A reevaluation of the preceding, as well as other items under icing conditions, will be conducted during the 1980/1981 season.

2. This Directorate is in agreement with the report findings, recommendations and conclusions except as indicated. However, the following comments are provided relative to corrective actions and are directed to the report paragraphs as indicated.

a. Paragraph 55a: Failure of the droop stops to return to the static position is serious and exposes ground personnel to undue risk during shut down. Additionally, failure of the droop stops to engage could result in significant blade flapping during high wind conditions and subsequent air vehicle damage or personnel injury. Sikorsky Aircraft has designed a droop stop configuration which incorporates an anti-ice heater. This new configuration will be evaluated during the 1980/1981 icing season.

b. Paragraph 55b: Failure of the anti-flapping restrainers to return to the static position is not considered a deficiency in itself, in that correction of the deficiency related to failure of the droop stops to return to the static position should alleviate excessive flapping and rotor blade droop.

c. Paragraph 56. Interference between the main rotor blade trailing edge and the ALQ-144 IR countermeasures device results from failure of the droop stops to resposition during shutdown as well as abnormal control positioning. Incorporation of a stronger heated droop stop will significantly reduce the probability of contacting the ALQ-144 IR device with the main rotor blade trailing edge.

d. Paragraph 57a: The large increases in power required resulting from ice accumulation on the rotor blades are fairly significant. A new schedule for blade deicing cycle off times is planned for the 1980/1981 icing season which may offer some improvement. Purpose is to alleviate ice accumulation and reduce the power increases associated with operation of the main rotor deicing system.

e. Paragraph 57b: Large power available losses can be expected when operating the engine and engine inlet anti-ice systems. However, it should be pointed out that the inlet anti-ice values were either full open or full close during the icing tests. For the production configuration the valves will be modulated based on ambient temperature. The production valve configuration will be available and evaluated during the 1980/1981 icing season tests. It is anticipated that the loss in power available when operating the production values will be less since the openings will be modulated by temperatures and not remain in full open when activated.

f. Paragraph 57c: The deice system circuit breakers will not be relocated because the benefit of a cockpit location does not balance the cost for a normal crew of three.

g. Paragraph 57d: The deice system operational check requires approximately five minutes to complete while the rotor speed is at 100% RPM. This is considered excessive. Sikorsky Aircraft has modified the helicopter wiring so that most of the operational check procedure will be accomplished with only the APU running. The new procedures will be evaluated during the 1980/1981 icing season.

h. Paragraph 57e: The poor reliability of the deice system is not considered significant at this time since most deice system components were of the prototype configuration. The production configuration, and hence the reliability. will be established at a later date.

i. Paragraph 57f: The inadequacy of the drip pan has been previously identified with corrective action taken. A modified drip pan with increased drain capacity is being incorporated on the first 124 aircraft and a redesigned drip pan with increased dump and drain capacity incorporated on aircraft S/N 79-23319 and subsequent. The improvements to the drip pan could not be evaluated due to interference with installed instrumentation.

j. Paragraph 57g: The high aircraft 4/rev vibration levels during a transition to landing are inherent. While the 4/rev vibration levels exceed specification requirements for the pilots station and engine exhaust frame, they are transitory.

k. Paragraph 57h: The inadequate water tightness of the cockpit is a quality control problem which has been corrected on all but the earliest aircraft.

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l. Paragraph 57i: A repositioned icing rate meter which is canted 15 degrees for better readability by the copilot will be evaluated during the 1980/1981 icing season as a prototype installation.

m. Paragraph 57j: The inadequate cabin heat distribution appears to be a quality control manufacturing problem and not necessarily a design problem. The doors and covers of the UH-60A are not adequately sealed thereby causing cold drafts and heat loss and subsequently inadequate cabin heat distribution.

n. Paragraph 57k: The unreliable tail wheel lock and unlock indications do not affect the actual operation of the tail wheel lock and unlock features. Since the crew has control over locking and unlocking and the lock/unlock operation clearly follows the switch position, the unreliable indications are nuisance type problems under some environmental conditions.

o. Paragraph 57l: Ice accumulation on the cockpit steps is not desirable however, since the exposure time to ice accretion under operational conditions is slight and attention to egress procedures is practical, a redesign of the steps is not considered cost effective. A caution in the Operators Manual can be used to advise the crew of ice accumulation on the steps.

p. Paragraph 57m: A design change to the jumper assemblies which should eliminate the bonding failures has been incorporated into production aircraft and will be evaluated during the 1980/1981 icing season.

q. Paragraph n: Ice accretion on the FM homing antenna does not create a serious problem when opening the cockpit door. A note in the Operator's Manual can be used to advise the pilot that a slight pressure on the door will break off the ice.

r. Paragraph 59a: The vibration level at the pilot's location was a shortcoming and described as moderate. Since the vibrations were transitory, they were acceptable even though specification compliance was not met.

s. Paragraph 59b: The report data indicates that under some conditions, the vibrations at the engine exhaust frame exceed specification limits. The high engine vibration levels have also been measured during contractor testing. Currently, the US Army, Sikorsky Aircraft and General Electric are evaluating vibration data obtained under the US Navy SeaHawk program. It is expected that a resolution regarding engine vibration exceedances will be made at a later date following the evaluation of SeaHawk vibration data.

t. Paragraph 63: The production engine inlet anti-ice value will be evaluated during the 1980/1981 icing season.

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u. Paragraphs 65, 66, 68, 69, 70 and 71: The caution and notes contained in these paragraphs will be incorporated, where appropriate, but following the 1980/1981 icing season test results.

3. The subject report represents an excellent evaluation of the UH-60A icing capability by the US Army Aviation Engineering Flight Activity (USAAEFA). As a result of the USAAEFA evaluation, several improvements are required to insure airworthiness operations under icing conditions. These improvements will be evaluated during the 1980/1981 icing season prior to the release of any production design kit.

FOR THE COMMANDER:

CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

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INTRODUCTION

BACKGROUND

1. The US Army requires that the UH-60A Black Hawk helicopter operate safely in an icing environment through a moderate level of intensity (ref 1, app A). Artificial icing tests were conducted previously in Alaska in 1976 by the United States Army Aviation Engineering Flight Activity (USAAEFA) using a prototype YUH-60A equipped with a main and tail rotor deice system and anti-icing equipment for the pilot and copilot windshields, pitot-static tubes and support fairings, engines, and engine inlets (ref 2, app A). Additional limited artificial icing tests of a production UH-60A with similar deice and anti-icing systems installed were conducted in Minnesota in 1979 (ref 3, app A). The production UH-60A incorporated improved main and tail rotor deice and anti-icing systems. Additional artificial and natural icing tests were required to qualify these systems for operational use in a moderate icing environment. The United States Army Aviation Research and Development Command (AVRADCOM) directed the USAAEFA to conduct artificial and natural icing tests of the production UH-60A helicopter (ref 4, app A) during the winter of 1979-1980 in accordance with the approved test plan (ref 5, app A).

TEST OBJECTIVES

2. The objectives of this test were to conduct artificial and natural icing flight tests of the production UH-60A helicopter to:

a. Substantiate the effectiveness of the production anti-ice and deice systems

b. Determine the effectiveness of the ice detection subsystem

c. Evaluate the effect of ice accumulation on the UH-60A helicopter handling qualities and performance

d. Provide data for inclusion in the operator's manual

DESCRIPTION

3. The UH-60A is a twin-turbine, single-main-rotor configured helicopter capable of transporting cargo, 11 combat troops, and weapons during day or night visual meteorological conditions (VMC) or instrument meteorological conditions (IMC). Non-retractable wheel-type landing gear are provided. The main and tail rotors are both four bladed, with a capability of manual main rotor blade and tail pylon folding. A movable horizontal stabilator is located on the tail rotor pylon. The deice system consisted of an outside air temperature sensor, ice detector, icing rate meter, blade deice control panel, and fault monitor panel. Also included were slip rings mounted on the main and tail gear boxes, deicing system junction boxes and a blade deice controller. The main and tail rotor blades contained resistive heating mats. Anti-ice systems were provided for the windshields, pitot-static tubes and their support struts, engines, and engine inlets. The test helicopter, serial number (S/N) 77-22717, was tested in both the infrared (IR) configuration with the IR suppressor kit (PN 770-30001-011), AN/ALQ-144 IR counter measures device and M-130 chaff dispenser installed, and in the normal utility configuration with standard engine

exhaust module and the M-130 installed. In the utility configuration the deswirl duct (PN 70070-30011-108) was installed. The deice system contained a preproduction fault monitor panel (PN X7006-80055-041), preproduction current transformers, a preproduction Rosemount icing rate meter (PN 70550-01124-101, SN 0002) and a slightly modified tail rotor slip ring assembly. The engine inlet anti-ice system was equipped with both the fixed orifice (PN 70306-10012-106) and the modulated orifice (PN 70306-10012-107) engine inlet anti-ice valves. A more detailed description of the UH-60A is contained in the operator's manual (ref 6, app A). A detailed description of the anti-ice and deice systems is presented in appendix B. A description of the helicopter icing spray system (HISS) installed on CH-47C helicopter, S/N 68-15814, is presented in ref 7, appendix A and appendix C.

TEST SCOPE

4. Inflight artificial and natural icing tests were conducted in the vicinity of St. Paul, Minnesota, from 11 February through 31 March 1980. A total of 31 flights were conducted totaling 52.2 hours. Of these flights 4 were in the artificial icing environment, totaling 6.9 hours, and 15 flights were in the natural environment, totaling 30.5 hours. Tests were conducted at average gross weights from 16,760 to 16,000 pounds with average longitudinal center of gravity (cg) locations from 355.6 to 353.4 inches. Lateral cg was 0.3 inches left. Pressure altitude varied from 1700 to 10,000 feet. Icing was accomplished at ambient temperatures from -4 to -21.5°C at liquid water contents (LWC) of 0.01 to 1.0 grams per cubic meter (gm/m^3). Test airspeed in the icing environment was 82 to 138 knots true airspeed (KTAS) and main rotor speed was 258 rpm (100 percent). Anti-ice and deice systems were operated continuously while in the icing environment. The aircraft was flown in the normal utility configuration and with the IR suppressor kit installed. A summary of icing test conditions is presented in table 1. Flight limitations contained in the operator's manual and the safety of flight release (ref 8, app A) were observed during the testing.

Table 1. Test Conditions[1]

NUMBER OF FLIGHTS	ENVIRONMENT	CONFIGURATION	AVERAGE STATIC OUTSIDE AIR TEMPERATURE (°C)	AVERAGE LIQUID WATER CONTENT (gm/g^3)	TRUE AIRSPEED (KTAS)	TIME IN CLOUD (hrs)	TIME FLIGHT TIME (hrs)
4	ARTIFICIAL ICING	IR Suppressed[2]	-3 to 21.5	0.25 to 1.0	82	3.7	6.9
3	NATURAL ICING	IR Suppressed	-7 to -12	0.02 to 0.24	120	3.1	6.0
11	NATURAL ICING	Clean[3]	-4 to -11	0.01 to 0.32	93 to 138	17.4	24.5
12	NON-ICING	IR Suppressed Clean	N/A	N/A	N/A	3.6[4]	14.8

NOTES: [1] Main rotor speed: 258 RPM
Average gross weight: 16,320 lb
Average center of gravity: longitudinal: FS354.3 in.; lateral: BL0.3 in. left
Range of pressure altitude: 1700 to 10,000 ft
[2] IR Suppressors, ALQ-144 IR Countermeasures Device, M-130 Chaff Dispenser
[3] Standard Tailpipes, M-130 Chaff Dispenser
[4] Productive flight time in VMC conditions

TEST METHODOLOGY

5. Artificial icing of the UH-60A was conducted by flying in a spray cloud generated by the HISS. Prior to entering the cloud, the test aircraft was stabilized at the predetermined test conditions and baseline trim data were recorded. The test aircraft was then immersed in the spray cloud. Data were recorded every five minutes while in the spray cloud. After a predetermined time of ice accumulation (15 min) the test aircraft was stabilized outside the spray cloud at the initial conditions and trim data were recorded. Ice accretion was documented by photographic and visual observation. When conditions permitted, a steady-state autorotation was performed to determine autorotative main rotor speed with ice accumulated on the aircraft. A detailed discussion of the test sequence and procedures is contained in reference 5, appendix A.

6. Natural icing tests of the UH-60A were conducted by flying in IMC icing conditions. Flights were conducted in accordance with instrument flight rules (IFR). All natural icing flights were conducted within the envelope of outside air temperature (OAT) and LWC previously established in the artificial environment. Close coordination with air traffic control and flight service stations was required to find and stay in the icing environment. In addition to the coordination, a combination of radar vectoring, navigational aid holding, and block airspace assignment was used to stay within the icing environment. Initial natural icing flights were accompanied by a support aircraft, flying in VMC below the clouds. At the termination of the natural icing encounter, the support aircraft crew recorded and photographically documented the ice accumulation. Trim data were recorded upon entry into the icing environment and every five minutes thereafter. When conditions permitted, a steady-state autorotation was performed to determine autorotative main rotor speed with the ice accumulated on the aircraft. Time in the clouds was limited by the availability of the natural conditions and aircraft IFR fuel requirements.

7. A USAAEFA-designed and fabricated visual ice accretion measuring device was used to observe the rate of ice accretion on the airframe. A high speed motion picture camera was mounted on the top of the aircraft, aft of the ALQ-144, and focused on the right hand portion of the stabilator. Test data were recorded on magnetic tape in both pulse code modulation (PCM) and frequency modulated (FM) format. A detailed description of special equipment and instrumentation is provided in appendix D.

8. Test techniques and data analysis methods are presented in appendix E. A Vibration Rating Scale (VRS), methods used to determine cloud parameters, and definitions of icing types and severities are also presented in appendix E.

RESULTS AND DISCUSSION

GENERAL

9. Artificial and natural icing flight tests of the UH-60A were conducted to substantiate the effectiveness of the deice and anti-ice systems. Flight control surface and airframe ice accumulation and shedding characteristics were documented and the effect of ice accumulation on the helicopter's performance and handling qualities was evaluated. A summary of the specific test conditions for each flight is presented in table 1, appendix F. Additionally the specific icing conditions in which the UH-60A was tested are presented in figure 1, appendix F for the artificial environment and figure 2, for the natural environment. The UH-60A Black Hawk helicopter, as configured for this test, demonstrated an excellent potential for operating in an icing environment. Three deficiencies were noted during the evaluation. The two icing related deficiencies noted during this test were: (1) failure of the droop stops to return to the static position during shutdown with ice accumulated on the main rotor head and (2) failure of the anti-flapping restrainers to return to the static position during shutdown with ice accumulated on the main rotor head. Upon correction of the two icing related deficiencies the UH-60A should have the capacity to operate safely in an icing environment through moderate intensities. One non-icing related deficiency was noted. The non-icing related deficiency was the interference between the main rotor blade trailing edge and the ALQ-144 with the droop stops in the incorrect shutdown position. In addition, fourteen shortcomings were identified, the most important of which were: (1) the large increases in power required with ice accumulation on the rotor system, (2) the large decrease in power available with engine and engine inlet anti-ice systems on, and (3) the poor location of the deice system circuit breakers. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.5.1.1.6 of the Prime Item Development Specification (PIDS), DARCOM-CP-2222-S1000D Part I in that, the failure of the droop stops and flap restrainers to return to the shutdown position precludes safe operation in a moderate icing environment. The two icing related deficiencies noted during this test should be corrected prior to further flight in icing conditions and the three shortcomings noted above should be corrected prior to production. The non-icing related deficiency should be corrected prior to operational release of the aircraft for flight with the ALQ-144 IR Countermeasure Device installed. The remaining shortcomings should be corrected.

DEICE SYSTEM OPERATION

General

10. The UH-60A helicopter deice system was evaluated for operational characteristics and effectiveness during 4.2 hours productive flight time in an artificial icing environment and 20.5 hours productive flight time in a natural icing environment. Conditions in which the system was tested are presented in table 1, appendix F. During testing in the artificial environment the operating mode of the system (Trace, Light, Moderate) was manually selected as a function of the LWC of the artificial cloud (app E). During testing in the natural environment the system was operated in the automatic mode. System on and off times, as a function of ambient air temperature and liquid water content, respectively, for the main and tail rotor blades are presented in figures 3 and 4, appendix F. During one flight in the artificial environment a manual mode of operation associated with a greater LWC than dictated by the actual LWC of the cloud was selected (Light rather than Trace and Moderate rather than Light). This resulted in an off time shorter than the automatic

schedule for these conditions and produced run back on the main rotor blades (photo 1, app H). No other evidence of rotor blade run back was documented during this evaluation. A deice cycle, that is, the period of time from the beginning of a deice electrical pulse to the beginning of the next system pulse, was characterized by an increase in engine torque of 4 to 12% and a rise in turbine gas temperature (TGT) of approximately 75°C (para 36). Following this rise in torque a noticeable increase in longitudinal and vertical vibrations at a frequency corresponding to two cycles per revolution (2/rev) of the main rotor was experienced while the heating pulses were applied to the main rotor blades (para 41). The vibrations then returned to the level prior to the heating pulses being applied to the rotor blades. Following the increase in vibrations engine torque and TGT returned to their previous values. With collective fixed and altitude held constant, indicated airspeed would decrease up to 12 KIAS during an ice accretion cycle. The increase in power required and vibration levels are discussed in paragraphs 36 and 41 respectively.

Ice Detection Subsystem

11. The ice detection subsystem consisted of a Rosemount aspirated ice detector mounted on the right engine nacelle and a Rosemount icing rate meter located on the pilot's instrument panel in the cockpit (app B). The effectiveness of the subsystem was evaluated in the natural icing conditions listed in table 1, appendix F. Due to the size of the HISS cloud (app C), the ice detector was not immersed in the artificial cloud and therefore was not evaluated during artificial icing conditions. In a natural icing environment, the visual ice detector indicated icing severity (app E) that closely agreed with the average indications on the icing rate meter observed by the flight crew. The icing rate meter indications appeared to reflect accurately the variations in LWC found in a natural icing environment and were damped sufficiently to permit the flight crew to note the changing LWC. Following one natural icing encounter, the aircraft was exited from the clouds with ice accumulated on the ice detector. The DEICE CONTROL PANEL power switch was turned OFF. The ice detector subsystem operated correctly to produce a signal that illuminated the ICE DETECTED caution capsule. Under the conditions tested, the ice detection subsystem operation is satisfactory. The ice detection subsystem indicates icing rates which appear to correlate with accepted icing severity definitions.

ANTI-ICE SYSTEM OPERATION

General

12. The UH-60A anti-ice systems were evaluated for operational characteristics and effectiveness during 4.2 productive flight hours in an artificial icing environment and 20.5 productive flight hours in a natural icing environment. Additionally, a comparison of engine inlet anti-ice valves was performed during 1.9 flight hours in a non-icing environment. All anti-ice systems were activated prior to entering the icing environment and were operational for all icing flights. The engine and engine inlet anti-icing systems were activated by placing the No. 1 and No. 2 ENG ANTI-ICE switches ON. Placing these switches on opened the engine anti-ice bleed valves and the engine inlet anti-ice valves. This increase in engine compressor bleed air required for anti-ice system operation caused a large decrease in engine power available (para 37).

Engine

13. Engine anti-icing was accomplished by a combination of hot axial compressor discharge air and heat transfer from the air/oil cooler in the engine frame. The system was controlled by the ENG ANTI-ICE switches located on the upper console. A detailed description of the system is presented in appendix B. The engines were borescoped daily and an engine health indicator test (HIT) was performed prior to every flight. No engine deterioration was identified during this program. There were no indications of ice accumulation in the engine and the system operated without failure. Within the scope of this test, the engine anti-ice system is satisfactory.

Engine Inlet

14. The engine inlet was anti-iced by hot engine bleed air which was controlled by the ENG ANTI-ICE switch. A system description is presented in appendix B. Two engine inlet anti-ice valves were evaluated. The fixed orifice nonmodulating valve (PN 70306-10012-106) was installed for all icing flights. The modulating valve (PN 70306-10012-107) was installed for a limited non-icing flight to evaluate engine characteristics and inlet surface temperature with this valve as compared to the nonmodulating valve. Engine characteristics for both the nonmodulating and modulating valves are presented in figures 5 through 10, appendix F. Inlet surface temperatures recorded during the limited -107 valve tests are compared to -106 valve data in figures 11 and 12, and at the ambient temperature tested, shows an approximate 15°C shift toward a cooler surface temperature with the modulating (-107) valves installed. Reduction in power available with operation of the engine inlet anti-ice system is discussed in paragraph 37. During flights in icing conditions, no ice was observed to accumulate on the anti-iced portions of the engine inlets. The system operated without failure or unscheduled maintenance. Although the modulated valves were evaluated for engine characteristics, they were not evaluated in icing conditions. Further testing of the modulated engine inlet anti-ice values should be accomplished in artificial and natural icing conditions to verify proper operation.

Windshield

15. The pilot and copilot windshields were electrically heated and controlled by individual switches on the upper console. A detailed discussion of the system is presented in appendix B. The windshield anti-ice was actuated for all icing flights. Two failures occurred in the artificial environment (app G). The first failure was as a result of unshielded sensor wires and the second as a result of a faulty control unit. The windshield anti-ice functioned to keep both the pilot and copilot windshield free of ice, moisture, and interior fogging. The windshield anti-ice system contains fault protection circuitry and an automatic shutoff feature which is activated if the auxiliary power unit (APU) generator is the only source of power and the backup hydraulic pump is ON. To regain system operation the WINDSHIELD ANTI-ICE switch must be cycled from ON to OFF and back to the ON position. The OFF position serves as a reset position although it is not labeled as such. The WINDSHIELD ANTI-ICE COPILOT and PILOT switches should be labeled to indicate the RESET feature of the OFF position.

16. The center plexiglas windshield was not anti-iced. Cockpit heating system outlets were rotated to direct heated air on the center windshield. This heating did

not keep the center windshield completely free of ice (photo 2, app H). The ice accumulation on the windshield minimally restricted the pilot's field-of-view. Within the scope of this test, the lack of center windshield anti-ice is satisfactory.

Pitot Tubes and Support Struts

17. The pilot and copilot pitot tubes and support struts were anti-iced electrically and controlled by a single PITOT HEAT switch located on the upper console. A system description is presented in appendix B. The pitot heat was activated for all flights in icing conditions. No ice accretion was observed and the system operated without failure. Within the scope of this test, the pitot tube and support strut anti-ice is satisfactory.

ELECTRICAL POWER REQUIREMENTS

18. The electrical power requirements for the deice and anti-ice systems were evaluated throughout these tests. The power requirements for the main and tail rotor deice systems as well as the windshield anti-ice systems associated with the respective generators for normal operation and emergency mode (assuming the Number 1 generator has failed) are presented in table 2, below. The automatic switching of generator loads for backup operations was evaluated and found to operate per the system description. The normal or emergency mode of operation of these systems never exceeded the power capabilities of the respective generators. For the conditions tested, the electrical power requirements of the deice and anti-ice systems are satisfactory.

Table 2. Electrical Power Requirements for the Deice/Anti-Ice Systems*

Component	Normal Operation			Emergency Operation (Generator 1 Failed)		
	Main	Tail	Windshields	Main	Tail	Windshields
Generator 1 load (amperes)	0	12	12	--	--	--
Generator 2 load (amperes)	50	0	11	0	0	23
APU generator load (amperes)	–	--	--	50	12	0

*All systems operate with 115 volt alternating current.

FLIGHT CONTROL SURFACE ICE ACCRETION AND SHEDDING CHARACTERISTICS

General

19. Flight control surface ice accretion and shedding characteristics were evaluated throughout these tests. Specific test conditions are listed in table 1, appendix F, and shown graphically in figures 1 and 2. No in flight difficulties associated with flight control surface ice accretion or shedding were identified. Following flight in icing conditions, the droop stops and anti-flapping restrainers failed to return to the shut-down position resulting in unsafe conditions and are both deficiencies. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.5.1.1.6 of the PIDS, DARCOM-CP-2222-S1000D Part I, in that the failure of the droop stops and flap restrainers to return to the shutdown position precludes safe operation in a moderate icing environment.

Main Rotor Blades

20. Ice accreted on the heated surfaces of the main rotor blades (app B) was observed to shed in the artificial icing environment. Data collected in the natural icing environment indicated that accumulated ice on the main rotor blades was sufficiently shed to return the engine power required to the preaccretion level. Ice did accumulate on some unprotected main rotor blade surfaces, photo 3, appendix H. The most obvious accretions were located on the leading edge of the blade inboard of the heating mat. Approximately 12 spanwise inches of leading edge ice was noted both in the artificial and natural environments. Small ice stalk accretions were observed after rotor shut-down on the lower surface of the blades aft of the protected areas. During the extremely cold (-20°C) artificial icing encounters, high speed photography indicated that ice accumulated on the unprotected swept tip caps. Upper surfaces of the main rotor blades aft of the protected areas and in the reverse flow region also accreted minimal amounts of ice. There were no significant increases in power required or difficulties associated with these ice accretions or their subsequent shedding from these unprotected areas. At the conditions tested, the main rotor blade ice accretion and shedding characteristics are satifactory.

Main Rotor Head

General:

21. A typical ice accumulation on the unprotected main rotor head is shown in photograph 4, appendix H. This specific photograph was taken after 90 minutes of exposure to natural icing conditions of -12.0°C and an average LWC of 0.09 gm/m^3. As much as 1 1/2 inches of ice accreted on sharp edged components during most icing exposures. Lesser thicknesses of ice were noted on flat surfaces and areas opposite the direction of rotation. After six of the natural icing encounters, the aircraft was descended below the freezing level for sufficient time to allow for complete deicing of the rotor head with no damage noted to the rotor blades or fuselage surfaces. There was no evidence of ice accumulation interference with main rotor blade spindle lead/lag or flapping. No evidence was found of restriction to bifilar motion or blade damper operation.

Droop Stops:

22. The main rotor blade droop stops were unprotected and accreted ice in the artificial and natural icing environments. A droop stop in the normal (no-ice) shutdown position is shown in photograph 5, appendix H. After an icing encounter the droop stop assembly and the resulting ice accretion is shown in photograph 6. The specific conditions associated with the referenced photograph were 90 minutes of average 0.09 gm/m^3 LWC at -12.0°C. During some shutdown sequences it was possible to force the droop stops to the static position by control manipulations. After the ground crewman had detected the droop stops incorrectly positioned with the engines at idle, the following procedure was followed: One of the two operating engines was shutdown resulting in a lower idle rotor RPM. Cyclic control motions of approximately ± 1 inch magnitude were made in an attempt to force the droop stops to the correct position. If the first two measures failed, collective pulses of approximately three inches of up collective were used. On three occasions all the above procedures failed and the aircraft was shut down with at least one droop stop in the incorrect position. No shutdowns with residual ice were accomplished with wind in excess of 20 knots. Several icing flights were cancelled due to high gusty winds and the uncertainty of proper droop stop operation. If the droop stops fail to properly operate the main rotor blade tip will clear level ground by 4 1/2 feet at the 12 o'clock position (photo 7, app H). On two occasions droop stops appeared to be very close to the full seated position but dropped out at low coast down rotor speed. Tail boom clearance with the droop stops out was approximately 2 1/2 feet. Shutdowns with the droop stops incorrectly seated will endanger ground personnel due to the close proximity of the blade tip to the ground under no wind conditions, and could damage the aircraft if shutdown were attempted under gusty or strong wind conditions. The failure of the droop stops to return to the static position during shutdown with ice accumulation on the main rotor head is a deficiency.

Flap Restrainers:

23. The main rotor anti-flapping restrainers were unprotected and accreted ice in the artificial and natural icing environments. An anti-flapping restrainer in the normal (no-ice) shutdown position is shown in photograph 8, appendix H. After an icing encounter the flap restrainer assembly is shown in photograph 9, with ice accreted and in the incorrect position. Following virtually every icing encounter listed in table 1, appendix F, the anti-flapping restrainers remained in the fly position during and after the shutdown procedure. Failure of these anti-flapping restrainers to operate and return to the correct position will allow the main rotor blades to flap excessively during shutdown in gusty or strong winds at low rotor speeds. Excessive flapping can allow sufficient blade motion under these conditions to damage the aircraft, particularly when combined with the droop stop deficiency discussed in paragraph 22. Failure of the anti-flapping restrainers to return to the static position during shutdown with ice accumulation on the main rotor head is a deficiency.

Tail Rotor

24. The tail rotor blades and hub area accreted ice in a similar manner in the artificial and the natural icing environments. The high rotation speed of the tail rotor prevented good photographic documentation of the accretion characteristics. Residual ice accumulations observed after shutdown indicated that complete shedding occurred along the heated portions of the tail rotor blades and little ice

remained on unprotected surfaces of the tail rotor blades. Ice accretions of over 1/2 inch in thickness remained on the tail rotor blade pitch change mechanisms and inner hub area after many icing encounters but did not present any problem either during operation or during subsequent shedding. Shed tail rotor ice accumulations impacted the upper surface of the stabilator at the intersection of the tail rotor tip path plane and the plane of the stabilator in the cruise position resulting in almost undetectable stabilator skin dents. For the conditions tested during this evaluation, the tail rotor ice accretion and shedding characteristics are satisfactory.

Stabilator

25. The ice accretion and shedding characteristics of the stabilator were evaluated throughout the program. Similar formations of ice were observed with the IR suppressors installed in the artificial icing and natural icing conditions. A typical artificial icing stabilator ice accumulation with the IR suppressors installed is shown in photograph 10, appendix H. Several instances of ice shedding from the stabilator were recorded with the movie camera mounted on the aircraft exterior. With the IR suppressors installed full span stabilator ice was accreted. These ice formations (as much as 2 inches thick) and the observed natural ice shedding did not interfere with normal aircraft system operation nor noticeably degrade the performance of the stabilator. Photograph 11, shows the ice formation typical of natural icing encounters with the standard tailpipe configuration. Significantly less ice was observed to form on the stabilator in this configuration when compared with the IR suppressed configuration. Similar beneficial effects of exhaust gas impingement have been observed in other aircraft icing evaluations. Again, natural ice shedding was observed in films taken with the onboard camera. For the conditions tested, the ice accretion and shedding characteristics of the stabilator are satisfactory.

AIRFRAME ICE ACCRETION AND SHEDDING CHARACTERISTICS

General

26. The airframe ice accretion and shedding characteristics of the UH-60A helicopter were evaluated in both the IR suppressor and standard tail pipe configurations at the specific test conditions of table 1, appendix F. Those characteristics were documented in both the artificial and natural icing conditions as depicted in figures 1 and 2, respectively. In-flight photographic documentation from a chase aircraft as well as on board photography was utilized. A typical in-flight photograph of the helicopter with ice accreted, photograph 12, was taken immediately after exiting the natural icing conditions. Specific test conditions for this photograph were 90 minutes of exposure to 0.09 gm/m^3 average LWC at -12.0°C. The ice accretions depicted in this photograph were indicative of all natural icing encounters during this evaluation. Ice formed on all stagnation areas and sharp protrusions from the airframe. Two shortcomings associated with the airframe ice accretion and shedding characteristics were the ice accretions on the cockpit steps and the ice accumulation on the FM homing antennas interfering with cockpit door opening.

Cockpit Steps

27. A typical residual ice accumulation on the cockpit step, after landing from a natural icing encounter is shown in photograph 13, appendix H. This photograph was taken approximately 20 minutes after exiting 90 minutes exposure to 0.09 gm/m^3 average LWC at -12.0°C. On most natural icing flights in which residual ice was present upon landing, the cockpit steps were obstructed by ice formations. The ice was configured in such a way as to cause the crew member's foot to slip from the step unless care was taken to step only on the forward portion of step which was not obstructed. The accumulation of ice on the cockpit steps is a shortcoming. It is recommended that the following warning be placed in the operator's manual:

WARNING

Following an icing encounter, the cockpit crew should be extremely careful when exiting the aircraft due to ice accumulation on the cockpit steps.

Unprotected Windows

28. The cockpit overhead windows, center windshield, check bubbles and cockpit door windows were not anti-iced other than by warm air defog provisions. Specific test conditions, in which the unprotected cockpit window ice accretion and shedding characteristics were evaluated, are is presented in table 1, appendix F. A typical cockpit center windshield residual ice accretion following a natural icing encounter of 95 minutes at -4.0°C with an average LWC of 0.32 gm/m^3 is shown in photograph 2, appendix H. All other listed cockpit viewing surfaces remained free of ice accretion at all natural icing test conditions listed even with cockpit defog off. The cockpit window defog capability prevented the windows from fogging at all conditions tested. Ice crystals formed on the center windshield. The ice accretion was not sufficient to completely restrict the pilot's field-of-view through this portion of the viewing surface since the accreted ice never completely covered the center windshield. No difficulties were identified with the ice shed from this area. The cockpit unprotected window ice accretion and shedding characteristics are satisfactory.

29. Unprotected window areas in the cabin area consisted of the gunner's sliding windows and the sliding cargo door windows. During several natural icing encounters, particularly when small ice particle size was suspected, these window surfaces were partially obscured by small ice crystal formations on the plexiglas surfaces. Ice formed on the sharp edges of the gunner's windows framework and on occasion reduced the amount of cold air which normally leaks into the cabin from this area. In all cases the windows and doors could be actuated during and following natural icing encounters. No difficulties were observed from ice shed from these accretion areas. At the conditions tested the ice accretion and shedding characteristics of the cabin unprotected windows are satisfactory.

Windshield Wipers

30. Windshield wiper ice accretion and shedding characteristics were evaluated at the test conditions shown in table 1, appendix F. A typical residual ice accretion on the pilot's windshield wiper mechanism is shown in photograph 14, appendix H. The test conditions for this photograph were approximately 65 minutes of natural ice accumulation at -7.5°C and an average LWC of 0.24 gm/m^3. Frequently, ice accumulations of over 3 inch thickness were present upon landing following natural icing encounters. Ice accretion on the windshield wipers was one of the pilot's first external visual indications of an icing encounter. Those ice accumulations were shed both naturally (descending below the freezing level) and deliberately (activating the windshield wiper system) in-flight. High speed photographic coverage was used to document the resultant ice particle paths. Outside observers from chase aircraft and the photographic coverage indicated that little if any of the shed ice was ingested into the engines. Borescoping of the engines after each day's icing indicated no engine damage due to ice ingestion. The windshield wipers operated each time they were activated even with ice accretions in excess of 3 inches on the sharp leading edge of the wiper mechanisms. For the conditions tested the windshield wiper ice accretion and shedding characteristics are satisfactory.

Fuselage

31. The fuselage ice accretion and shedding characteristics of the UH-60A helicopter were evaluated at the specific test conditions shown in table 1, appendix F. Natural icing accretions on the forward portions of the helicopter (forward of the engine inlets) were identical for the IR suppressed and standard tail pipe configurations. Somewhat less ice was accreted on the empennage with the standard tail pipe configuration as compared to the IR suppressor configuration (see para 25). A few of the common ice accretion areas were: an approximate two square foot area on the nose of the aircraft (photo 15, app H); the nose avionics compartment hinges and latches (same photo); the deice system OAT sensor cover (photo 16); the cockpit door hinge covers and handles; the ship's OAT sensor (photo 17); the cargo hook (photo 18); the leading edge at the tail rotor pylon (IR configuration) (photo 19); and many rivet heads and/or irregularities in the fuselage aerodynamic surfaces (photo 20). No operating difficulties were identified due to these ice accumulations or their subsequent shedding. All windows, doors and access panels remained functional after natural icing encounters except the cockpit doors as discussed in paragraph 33. The fuselage ice accretion and shedding characteristics are satisfactory for all conditions tested.

Engine Ice Ingestion

32. Ingestion of airframe and rotor system ice was evaluated throughout this program. Specific test conditions are presented in table 1, appendix F. Frequent instances of ice particles being ingested into the inlet of the T-700 engines were noted both in the artificial and natural icing environments. Chase aircraft and HISS crew members reported ice leaving the aircraft and being ingested by the engines. High-speed motion picture documentation also confirmed engine ingestion of ice particles at least the size of a quarter. No unusual cockpit engine indications were noted. Daily borescope checks of both engines failed to reveal any compressor damage throughout the evaluation. Large pieces of ice were intentionally shed from the windshield wipers to ensure that particles released in this operational manner would not be ingested in sufficient quantities to damage the engines. At the

conditions tested, the engine ice ingestion characteristics of the T-700 engines installed on the UH-60A helicopter are satisfactory.

Antennas

33. The ice accretion and shedding characteristics of the aircraft antennas was evaluated at the specific test conditions listed in table 1, appendix F. Many Black Hawk antennas are flush mounted and thus accrete little if any ice. Exceptions to this are the FM homing antennas aft of the cockpit doors (photo 21, app H), the VOR antennas on the tail boom (photo 22), and the number 1 FM antenna in the leading edge of the tail rotor pylon (photo 19). No degradation in aircraft radio transmission or reception was noted on any communications or navigation radios, although no specific tests were conducted to evaluate these characteristics. Ice shed from these antennas presented no operational difficulties. Residual ice built-up on the FM homing antennas on each side of the fuselage interfered with the normal opening of the cockpit doors. If approximately one inch of ice was still present when the door was opened a resistance was encountered requiring about 5 lbs on the door to break the ice away. The ice accumulation on the FM homing antennas which interfers with cockpit door opening is a shortcoming. The following note should be placed in the operator's manual prior to clearing the aircraft for operations in an icing environment:

NOTE

> Moderate accumulations (approximately one inch) of ice on the FM homing antennas can interfere with normal cockpit door opening. A slight amount of pressure on the door will normally break the ice from the antenna.

M-130 Chaff Dispenser

34. The ice accretion and shedding characteristics of the M-130 chaff dispenser were evaluated during artificial and natural icing conditions outlined in table 1, appendix F. A typical residual ice accretion documented after landing from a natural icing encounter of 105 minutes at -11.0°C and an average LWC of 0.06 gm/m^3 is shown in photograph 23, appendix H. The M-130 system was not operated during this evaluation. No ice accretions or subsequent sheds were observed which would interfere with the operation of the system during or after an icing encounter. For the conditions tested, the ice accretion and shedding characteristics of the M-130 chaff dispenser are satisfactory.

ALQ-144 IR Countermeasures Device

35. The ice accretion and shedding characteristics of the ALQ-144 IR countermeasures device were evaluated at the specific test conditions listed in table 1, appendix F. The ALQ-144 was only installed in the IR suppressed configuration and was not operational. All external components were identical to an operational system. Typical residual ice accumulations for artificial and natural icing encounters are shown in photographs 24 and 25, appendix H respectively. Evaluating ice

accumulation on the operating characteristics of the ALQ-144 was beyond the scope of these tests. The resulting ice accumulations and subsequent sheds from the ALQ-144 did not adversely affect the operation of the helicopter in either the natural or artificial icing environments. Within the scope of these tests the ice accretion and shedding characteristics of the ALQ-144 IR countermeasures device are satisfactory.

PERFORMANCE

Level Flight Performance

36. Level flight performance characteristics of the UH-60A helicopter were evaluated at the specific test conditions listed in table 1, appendix F. These performance characteristics were documented before, during and after ice accretion on the helicopter. Figures 13 through 15 are typical time histories of ice accretions over at least one full deice cycle in various icing environments. Indicated torque increases of 4 to 12 percent were documented. For example, note the power required increase shown in figure 15, where the test conditions were an average gross weight of 16,560 lbs., density altitude of 2200 ft, average OAT of -7.5°C and LWC varying from 0.6 to 0.15 gm/m^3. The 12 percent indicated torque required increase shown represents a 22 percent increase in power above the power required to fly with the same collective setting with no ice accumulated. Each time the deice system cycled (approximately every 4 minutes for this example) the power decreased to the no ice accreted value set at the beginning of the icing encounter. From figure 15, the 22 percent increase in power above the no ice condition required an increase in fuel flow of 16 percent and a 6.5 percent increase in TGT. Over an entire flight the average increase in fuel flow would be approximately 8 percent for these icing conditions due to ice accretion on the rotor systems. These power fluctuations were particularly disconcerting to the pilot since typically the engine power indications remain steady during collective fixed IFR operations when icing conditions are not encountered. Care must be taken to initially set the cruise power with no ice accreted at a sufficiently low level such that the possible 75°C increase in TGT accompanying the torque rise will not encounter the TGT limiter at 840°C and result in drooping the rotor speed. Rotor droops of 3 percent were experienced during this evaluation when the power was initially set too high. The approximate 8 percent increase in fuel flow will reduce the endurance capabilities of the helicopter by a similar amount and reduce the range capabilities probably by a slightly larger amount. The large increases in power required with ice accumulation on the rotor systems of the UH-60A helicopter is a shortcoming. The following NOTE should be placed in the operator's manual prior to release of the aircraft for operations in an icing environment.

NOTE

> During flight in icing conditions large engine torque increases (as much as 12% per engine) can be expected. The pilot should closely monitor engine instruments to prevent exceeding engine limits and/or drooping the rotor.

Power Loss with Operation of Anti-Ice Systems

37. Engine power loss characteristics with operation of the anti-ice systems were evaluated throughout these tests. The referred engine characteristics of both T-700 engine configured with the -106 and -107 engine inlet anti-ice valves are presented for comparison in figures 5 thru 10, appendix F. No detectable difference was found between the referred engine characteristics of the IR suppressed and the standard tail pipe configurations. Of particular interest are the increases in TGT and fuel flow associated with the anti-ice system operation. Typically an approximate 100°C rise in indicated TGT was observed in the cockpit due to turning on the engine and engine inlet anti-ice as well as the bleed air heater. A slightly lower increase (by approximately 15°C) was observed with -107 engine inlet anti-ice valves installed. The increase in TGT reduced the amount of available engine torque at which continuous TGT limits were encountered. The reduction in maximum continuous power resulted in a 15 to 20 knot decrease in cruise airspeed. Increases in fuel flow of 50 lb/hr were typical at all power settings with anti-ice bleed system actuation. This represents an approximate 10 percent increase in IMC (icing) cruise fuel flow which is additive to the performance penalties discussed in the previous paragraph. The installation of the -107 engine inlet anti-ice valve resulted in only an 8% rise in fuel flow for the specific conditions evaluated. No icing tests were conducted to verify engine inlet anti-ice capability although inlet surface temperatures were monitored at the inlet 12 o'clock position 2 inches aft of the stagnation point on the outside of the inlet (photo 5, appendix D) and the results are shown in figures 11 and 12. An approximate 15°C decrease in inlet surface temperature was noted with the decreased bleed air flow at the tested OAT, although the surface temperature always remained above freezing even at low power settings. The large power required increases (para 36) and the large power available losses discussed here will significantly effect the range and endurance characteristics of the UH-60A helicopter. For the conditions tested, the large decrease in power available with engine and engine inlet anti-ice system operation is a shortcoming. Further tests should be conducted to fully evaluate the -107 engine inlet anti-ice valve operation in an icing environment. The following NOTE should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment.

NOTE

> Significant power available losses can be expected with the actuation of the engine and engine inlet anti-ice systems.

Autorotational Descent Performance

38. Autorotational descent performance characteristics were evaluated at selected conditions after icing encounters in both the artificial and natural icing environments. The rotor speeds and descent rates observed after ice accumulations were compared with these parameters under no ice conditions. The maximum decrease in autorotational rotor speed with full down collective observed in the artificial environment occurred after 30 minutes exposure to 0.5 gm/m^3 LWC, 15 minutes exposure to 0.75 gm/m^3 LWC and 15 minutes exposure to 1.0 gm/m^3 at -20°C. All conditions were run consecutively and thus the ice accretion was cumulative. The largest rotor speed loss noted was from 105 percent (no-ice) to 101 percent with ice. After a natural icing encounter which produced the most increased power required,

with the collective fixed, (12% increase in indicated torque per engine) an autorotational RPM comparison was made in clear air conditions. The rotor speed was again reduced by 4 percent from 106 percent nominal no ice to 102 percent rotor speed with ice accreted. No change in autorotational descent rate was noted between the ice free and ice accreted on the rotor system conditions. Using the rotor speed information contained in the maintenance test flight manual (ref 10, app A) for trends, it should be possible to maintain the rotor speed within the limits specified in the operator's manual with ice accreted even at light gross weight and low altitude conditions. For the conditions tested, the autorotational descent performance characteristics of the UH-60A helicopter following an icing encounter are satisfactory.

HANDLING QUALITIES

General

39. The effect of airframe and flight control surface ice accretion on the aircraft handling qualities was qualitatively evaluated throughout all the icing flights at the conditions listed in table 1, appendix F. The evaluation was accomplished by performing typical instrument flight maneuvers with and without ice on the aircraft. No degradation of aircraft handling qualities were noted as a result of aircraft ice accretion.

Ground Handling

40. During ground operations in a freezing environment when the aircraft was subjected to moisture in the form of blowing snow or liquid water the tail wheel lock and indicating mechanism produced unreliable cockpit indications. The unreliable tail wheel lock and tail wheel unlock indications in a wet and freezing environment is a shortcoming. The following NOTE should be placed in the operator's manual as soon as possible.

NOTE

> During operation in cold weather, particularly when snow or moisture is present, the tail wheel lock, unlock and transient cockpit indications may be unreliable.

VIBRATION

Deice Cycle Vibrations

41. The aircraft vibration characteristics were monitored throughout these evaluations. Qualitative pilot comments and quantitative vibration data were compiled during natural ice cloud immersions. Figure 16, appendix F depicts a full deice system cycle to include the off time period of approximately 3 minutes. Spectral analysis plots of a main rotor deice cycle at various aircraft accelerometer locations are presented in figures 17 through 26 of appendix F. The observed and recorded vibration levels at the pilot station did not markedly change during the ice accretion phase of the cycle. During the main rotor deice cycle (fig. 16), the vibration levels at

the 2/rev frequency did increase appreciably in all three axes,but were most pronounced in the vertical axis. Little change was noted at any other rotor harmonic. These increased 2/rev vibration levels, although qualitatively noticeable, were of sufficiently short duration to cause little concern. A rating of 4 was assigned those vibrations on the VRS shown in figure 1, appendix E. After the flight crew has experienced several icing encounters and becomes familiar with this characteristic, the vibration increase becomes more of an assurance that the system is operating effectively than an annoyance. For the conditions tested the deice cycle vibration characteristics are satisfactory.

Transition to Landing

42. Although not a specific test objective, vibration levels at various aircraft locations were documented during transition to a hover from forward flight. Figures 27 and 28, appendix F represent the 4/rev vibration levels recorded during a typical normal approach to a hover as a function of indicated airspeed for the pilot seat pan and the engine exhaust frames respectively. The increased 4/rev vibrations were particularly noticeable to the pilot between approximately 35 KIAS and 10 KIAS. Worst case vibration levels recorded were 0.25 g vertical, 0.55 g lateral and 0.25 g longitudinal at the 4/rev frequency when passing through 20 KIAS. Figure 28 depicts the engine exhaust frame vibrations recorded during this same maneuver. The number 2 engine exhaust frame 4/rev maximum total transient vibrating velocities of 2.2 in/sec longitudinally and 7.5 in/sec vertically exceed the PIDS (ref 9, app A) requirements of 7 inches/sec vertically and 1.5 inches/sec longitudinally at 20 KIAS while transitioning to a landing. These recorded vibration levels were qualitatively evaluated as moderate and assigned a 6 on the VRS. The high 4/rev aircraft vibration levels observed during a transition to landing are a shortcoming. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.1.1.3.1.4 of the PIDS (ref 1), in that the 0.25g vertical, 0.55g lateral, and 0.25g longitudinal vibration levels at the 4/rev frequency exceed the 0.2g requirement while transitioning from forward flight to a hover. The UH-60A Black Hawk helicopter fails to meet the requirements of note 8d of Drawing No. 6021T99 of the PIDS, AMC-CP-2222-02000, specification for the T700-GE-700 Turboshaft Engine (ref 9) in that the 2.2 in/sec longitudinal and 7.5 in/sec vertical vibration velocities at the 4/rev frequency exceed the requirements of 1.5 in/sec longitudinally and 7.0 in/sec vertically at the engine exhaust frame during transition from forward flight to a hover.

HUMAN FACTORS

Deice System Circuit Breakers

43. There were four deice system circuit breakers located on the mission readiness circuit breaker panel mounted in the forward left cabin overhead. The mission readiness circuit breaker panel is inaccessable to the pilot and copilot while in flight. The minimum crew required for flight is the pilot and copilot. During flight in icing conditions if one of the deice system circuit breakers popped, the flight crew would be unable to regain the deice system by resetting the affected circuit breaker. The poor location of the deice system circuit breakers is a shortcoming.

Deice System Operational Check

44. The deice system operational check is performed as a part of the engine runup (ref 6, app A). The procedures followed to accomplish the operational check are contained in reference 4. These procedures require multiple actuation of four switches and simultaneous observation of five indicator lights and the clock. The operational check requires five minutes to complete and the undivided attention of at least one flight crew member for this period. The excessively long and complicated deice system operational check is a shortcoming.

Watertightness of Cockpit

45. After flight in an icing environment when the aircraft descended below the freezing level to warmer than freezing temperatures, the ice which had accumulated on the aircraft melted and water leaked into the cockpit from around the pilot doors and through the upper console and upper circuit breaker panels. The water which leaked into the cockpit was not only an annoyance to the flight crew but could damage electrical equipment. The inadequate watertightness of the cockpit is a shortcoming.

Icing Rate Meter Location

46. The icing rate meter was located with the deice control panel and fault monitor panel on the right center of the instrument panel (photo 26, app H). Because of the parallax from the copilot's station and the recessed face of the icing rate meter, the copilot could not monitor the meter indication when the indicated LWC was below 0.25 gm/m^3. During flight in icing conditions, the pilot is occupied flying the aircraft and the copilot is responsible for systems operation. The copilot cannot adequately monitor the intensity of the icing environment. The poor readability of the icing rate meter from the copilot station is a shortcoming.

Cabin Heat Distribution

47. The cockpit and cabin of the UH-60A is heated by a bleed-air system. The heated air is distributed by a blower through the cockpit and cabin ducting. There are two heat outlets in the cabin, located on the left and right forward cabin overhead (ref 6, app A). Under all combinations of cockpit heat outlet position (open or closed), cabin heat outlet position (open or closed), and heater control setting from OFF to HI, the cockpit area was consistently warmer than the cabin area. The difference in temperature was such that the copilot and pilot were uncomfortably warm when attired in flight suit and winter weight flight jacket while the flight test engineer, occupying a crew seat at fuselage station 282 (jump seat), was uncomfortably cold. The engineer was attired in thermal underwear, flight suit and winter weight flight jacket. The inadequate cabin heat distribution is a shortcoming.

RELIABILITY AND MAINTAINABILITY

Reliability of Deice System

48. During this flight test program, which consisted of 52.2 flight hours, there were six failures of the deice system: one failure of the icing rate meter; two deice system

failures associated with the main rotor components; and three deice system failures associated with the tail rotor components (app G). Of the two failures of the main rotor deice system, the first required changing the deice system controller and the fault monitor panel. The second main rotor deice failure was caused by a broken ground wire in the main rotor distributor which resulted in failure of the deice controller. The wire was repaired and the controller replaced. Of the three tail rotor deice failures, one was caused by a broken wire in the tail rotor slip ring. This occurred after approximately 150 hours of flight time on this component. The tail rotor slip ring was replaced. The second failure of the tail rotor deice components was caused by a worn brush assembly. Again this component had approximately 150 flight hours. The brush assembly was replaced. The third failure of the tail rotor deice components was caused by a faulty deice controller. The controller was replaced. The poor reliability of the deice system is a shortcoming.

Jumper Assembly, Bonding

49. During this test program, four failures of a jumper assembly, bonding (PN 70103-08031-042) occurred. The jumper assembly is required to dissipate any static charge on the tail rotor blades into the airframe rather than dissipate this charge through the bearings in the pitch change links. The high incidence of jumper assembly, bonding failures is a shortcoming.

MISCELLANEOUS

Main Rotor Blade Interference

50. Since improper droop stop and flap restrainer operation in the icing environment was identified, limited static rotor blade to ground and fuselage clearance measurements were accomplished. These tests were conducted with external electrical power applied to the helicopter and hydraulic power was obtained from the aircraft backup hydraulic pump. No in-flight blade clearance tests were conducted. With the droop stops in the fly position and full up collective with the remaining controls in a neutral position the trailing edge of the main rotor blade will contact the ALQ-144 IR countermeasures device as shown in photograph 27, appendix H. With 50% up collective, full application of left lateral cyclic, aft longitudinal cyclic, and left pedal control will also cause main rotor blade trailing edge to ALQ-144 contact. With a droop stop in the incorrect position for shutdown the pilot's natural tendency is to attempt to control the rotor tip path plane to ground clearance by applying left aft cyclic control. Application of collective pitch control (para 22) in an attempt to cause the droop stops to return to the static position completes the necessary sequence of events which could lead to main rotor blade trailing edge to ALQ-144 contact. The interference between the main rotor blade trailing edge and the ALQ-144 IR countermeasures device with the droop stops in the incorrect shutdown position is a deficiency. The following caution should be placed in the operator's manual prior to release of the aircraft for flight with the ALQ-144 IR countermeasures device installed:

CAUTION

If the aircraft must be shut down with the droop stops out and the ALQ-144 IR countermeasures device installed, the flight controls should be held in the neutral position with full down collective to prevent the possibility of main rotor blade trailing edge contact with the ALQ-144.

Actuation of the Anti-Ice Systems

51. The actuation characteristics of the anti-ice/bleed air systems were evaluated throughout these tests. Time histories of turning the engine and engine inlet anti-ice systems ON and OFF for both the -106 and -107 engine inlet valve configurations are presented in figures 29 through 32, appendix F. Both valves exhibited similar characteristics in that approximate ±2.5 deg/sec yaw rate oscillation developed which completely damped in approximately 1.5 cycles. The yaw oscillations were most noticeable to the pilot although approximately equal roll rates were recorded. The yaw and roll excursions observed were initially disconcerting in that the accompanying changes in engine/rotor noise and attitude changes were similar to some engine malfunctions. Unless all crew members are anticipating these oscillations and engine noise changes, moments of surprise and instinctive engine failure immediate action items (lowering collective and controlling rotor speed) can be initiated. Crew coordination prior to system actuation can minimize the surprise associated with these events. For the conditions tested the anti-ice/bleed air system actuation characteristics are satisfactory.

Main Transmission Drip Pan

52. Many icing encounters resulted in residual ice accretions on the main rotor head after shutdown. When the residual ice melted, water dripped around the main rotor transmission into the main transmission drip pan assembly. Even the melting of small accretions of ice exceeded the drain capacity of the drip pan assembly. Excess water above the pan drain capacity overflowed into the cabin area soaking the interior fabric materials and objects located beneath the transmission area (data package) photograph 28, appendix H. The insufficient main transmission drip pan drain capacity is a shortcoming.

CONCLUSIONS

GENERAL

53. The UH-60A Black Hawk helicopter configured with the anti-ice and deice systems tested, demonstrated an excellent potential for operating in an icing environment. Upon correction of the deficiencies noted, the UH-60A should have the capability to operate safely in icing through moderate conditions. During this evaluation, three deficiencies, fourteen shortcomings and one specification noncompliance item were identified.

SPECIFIC

54. The following specific conclusions were reached upon the completion of the UH-60A artificial and natural icing tests:

a. Flight in icing conditions does not noticeably change the handling qualities of the UH-60A helicopter (para 39).

b. The range and endurance characteristics of the UH-60A helicopter are significantly degraded during flight in icing conditions (para 36 and 37).

c. The ice detection subsystem indicates icing rates which appear to correlate with accepted icing severity definitions (para 11).

DEFICIENCIES

55. The following two deficiencies were identified in an icing environment and are listed in decreasing order of importance:

a. Failure of the droop stops to return to the static position during shutdown with ice accumulation on the main rotor head (para 22).

b. Failure of the anti-flapping restrainers to return to the static position during shutdown with ice accumulation on the main rotor head (para 23).

56. The following deficiency was identified in a non-icing environment:

Interference between the main rotor blade trailing edge and the ALQ-144 IR countermeasures device with a droop stop in the incorrect shutdown position (para 50).

SHORTCOMINGS

57. The following shortcomings were identified and are listed in decreasing order of importance:

a. The large increases in power required with ice accumulation on the rotor system (para 36).

b. The large decrease in power available with the engine and engine inlet anti-ice systems on (para 37).

c. The poor location of the deice system circuit breakers (para 43).

d. The excessively long and complicated deice system operational check (para 44).

e. The poor reliability of the deice system (para 48).

f. The insufficient main transmission drip pan drain capacity (para 52).

g. The high aircraft 4/rev vibration levels during a transition to landing (para 42).

h. The inadequate watertightness of the cockpit (para 45).

i. The poor readability of the icing rate meter from the copilot station (para 46).

j. The inadequate cabin heat distribution (para 47).

k. The unreliable tail wheel lock and unlock indications in a wet and freezing environment (para 40).

l. The ice accumulation on the cockpit steps (para 27).

m. The high incidence of jumper assembly, bonding failures (para 49).

n. The ice accumulation on the FM homing antennas which interferes with cockpit door opening (para 33).

SPECIFICATION COMPLIANCE

58. The following specification non-compliance was identified in the icing environment during this evaluation. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.5.1.1.6 of the PIDS, DARCOM-CP-2222-S1000D Part I, in that, the failure of the droop stops and flap restrainers to return to the shutdown position precludes safe operation in a moderate icing environment (para 19).

59. The following specification non-compliances were identified in a non-icing environment during this evaluation:

a. The UH-60A Black Hawk helicopter fails to meet the requirements of paragraph 3.2.1.1.3.1.4 of the PIDS, DARCOM-CP-2222-S1000D Part I, in that, the 0.25 vertical, 0.55g lateral and 0.25g longitudinal vibration levels at the 4/rev frequency exceed the 0.2g requirement while transitioning from forward flight to a hover (para 42).

b. The UH-60A Black Hawk helicopter fails to meet the requirements of note 8d of Drawing No. 6021T99 of the PIDS, AMC-CP-2222-02000, Specification

for the T700-GE-700 Turboshaft engine in that the 2.2 in/sec longitudinal and 7.5 in/sec vertical vibration velocities at the 4/rev frequency exceed the requirements of 1.5 in/sec longitudinally and 7.0 in/sec vertically at the engine exhaust frame during transition from forward flight to a hover (para 42).

RECOMMENDATIONS

60. The deficiencies listed in paragraph 55 a and b should be corrected prior to release of the UH-60A helicopter for operation in an icing environment.

61. The deficiency listed in paragraph 56 c should be corrected prior to release of the UH-60A helicopter for operation with the ALQ-144 IR countermeasures device installed.

62. The shortcomings listed in paragraph 57 a through c should be corrected prior to release of the UH-60A helicopter for operation in an icing environment.

63. Further tests should be conducted to fully evaluate the modulating (-107) engine inlet anti-ice valve operation in an icing environment (para 14).

64. The shortcomings listed in paragraph 57 d thru n should be corrected.

65. The following WARNING should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment (para 27):

WARNING

> Following an icing encounter, the cockpit crew should be extremely careful when exiting the aircraft due to ice accumulation on the cockpit steps.

66. The following CAUTION should be placed in the operator's manual prior to release of the aircraft for operation with the ALQ-144 IR countermeasures device installed (para 50):

CAUTION

> If the aircraft must be shut down with the droop stops out and the ALQ-144 IR countermeasures device installed, the flight controls should be held in the neutral position with full down collective to prevent the possibility of main rotor blade trailing edge contact with the ALQ-144.

67. The WINDSHIELD ANTI-ICE COPILOT and PILOT switches sahould be labeled to indicate the RESET feature of the OFF position (para 15).

68. The following NOTE should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment (para 36):

NOTE

> During flight in icing conditions large engine torque increases (as much as 12% per engine) can be expected. The pilot should closely monitor engine instruments to prevent exceeding engine limits and/or drooping the rotor.

69. The following NOTE should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment (para 37):

NOTE

Significant power available losses can be expected with the actuation of the engine and engine inlet anti-ice systems.

70. The following NOTE should be placed in the operator's manual as soon as possible (para 40):

NOTE

During operation in cold weather, particularly when snow or moisture is present, the tail wheel lock, unlock and transient cockpit indications may be unreliable.

71. The following NOTE should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment (para 33):

NOTE

Moderate accumulations (approximately one inch) of ice on the FM homing antennas can interfere with normal cockpit door opening. A slight amount of pressure on the door will normally break the ice from the antenna.

APPENDIX A. REFERENCES

1. Prime Item Development Specification, "DARCOM-CP-2222-S1000D Part I", 15 October 1979.

2. Final Report, USAAEFA Project No. 76-09-1, *Artificial Icing Test Utility Tactical Transport Aircraft System (UTTAS) Sikorsky YUH-60A Helicopter*, February 1977.

3. Letter Report, USAAEFA Project No. 78-05, *Artificial and Natural Icing Tests, Production UH-60A Helicopter*, 12 October 1979.

4. Letter, AVRADCOM, DRDAV-DI, 14 September 1979, subject: Artificial and Natural Icing Test of the Production UH-60A (Phase 2) (A&FC).

5. Test Plan, USAAEFA Project No. 79-19, *Artificial and Natural Icing Tests Production UH-60A Helicopter*, October 1979.

6. Technical Manual, *Headquarters, Department of the Army, UH-60A, Operator's Manual TM 55-1520-237-10*, 21 May 1970, with changes 1 - 4 and change 6.

7. Final Report, USAAEFA Project No. 79-93, *HISS Improvement*, unpublished.

8. Letter, AVRADCOM, DRDAV-DI, 18 January 1980, and 25 March 1980, subject: Airworthiness Release for UH-60A Black Hawk Helicopter, S/N 77-22717, to Conduct Artificial and Natural Icing Tests.

9. Prime Item Development Specification, AMC-CP-2222-0200A, *Specification for T700-GE-700 Turboshaft Engine*, 31 December 1973.

10. Technical Manual, Headquarters, Department of the Army, TM-55-1520-237-MTF, *UH-60A Helicopter, Maintenance Test Flight Manual*, 25 May 1979 with changes 1 through 5.

APPENDIX B. DESCRIPTION

ANTI-ICE SYSTEMS

General

1. The anti-ice systems installed on the UH-60A helicopter, SN 77-22717, used a variety of methods to provide ice protection. Engine bleed air was used to anti-ice the engine inlet and the engine. Additional engine anti-ice protection is provided by hot engine oil and the inlet particle separator (IPS) which offers limited protection from foreign materials such as ingested ice. Electrical energy is used to anti-ice the pilot and copilot windshields, the pitot tubes, and the struts that support the pitot tubes.

Engine Anti-Icing

2. Engine anti-icing is accomplished by a combination of hot axial compressor discharge air and heat rejection from the air/oil cooler integral to the main engine frame. A hot air anti-icing valve is electrically controlled by the ENG ANTI-ICE switch on the overhead panel. Anti-icing is off when electrical power is applied to the solenoid of the combination anti-icing and starting bleed valve assembly. Additionally, the valve will automatically open at an N_G less than 86 percent.

3. Axial compressor discharge air (station 2.5) is bled from the compressor casing at the 7 o'clock position, routed through the anti-icing valve, and delivered to the front frame and swirl frame via ducting. Front frame anti-icing air flows through a cored passage in the main frame to the front frame splitter lip, then exits to the main frame scroll and is discharged with IPS air. Within the swirl frame, hot air is ducted around the outer casing to each swirl vane. The hot air is circulated within each vane by a series of baffles, then exits from two areas. Approximately 90 percent of this hot air exits at the vane outer trailing edges. The other 10 percent exits through a series of circumferential slots in the swirl frame hub at the aft edge. This arrangement also acts as a "rain step" to preclude water from adhering to the hub and flowing into the compressor.

4. Anti-icing air is also ducted to the compressor inlet guide vanes (IGV's). A circumferential manifold surrounds the aft flange of the main frame to distribute hot air to the hollow IGV's. Slots in the trailing edge of the IGV's discharge this flow into the compressor inlet. Additionally, hot scavenge oil passing within the scroll vanes in the main frame precludes ice buildup which could result from moisture-laden IPS air.

Engine Inlet Anti-Icing

5. Engine inlet anti-icing is provided by hot axial compressor discharge air which is also electrically controlled by the ENG ANTI-ICE switch on the overhead panel. With the ENG ANTI-ICE switch ON, bleed air passes into inner and outer supply manifolds which are contained within the inner bullet nose and outer lip of the engine inlet. Anti-icing is then accomplished by a combination of convection and impingement as the bleed air flows between the flexible high-temperature fiberglass wall in the manifolds and the aluminum surface of the inlet. The entire surface of the inlet to the engine swirl frame, to include the bullet nose forebody and the fixed crotch section, is anti-iced in this manner. Exit provisions for the bleed air are provided through slots at the mouth of the inlet on the inboard side, plus an annular

slot in the inlet immediately ahead of the swirl frame. A small portion of the slot immediately ahead of the T_2 sensor is blocked so that hot anti-ice exit air would not give a false T_2 signal to the hydromechanical unit (HMU).

6. Two different engine inlet anti-ice valves were evaluated. One valve used a fixed orifice (PN-70306-10012-106) and was either open or closed as directed by the ENG ANTI-ICE switch position. The other valve (PN 70306-10012-107) was a modulating valve and controlled the volume of compressed air to the engine inlet as a function of outside air temperature.

Windshield Anti-Ice

7. The pilot and copilot windshields are electrically anti-iced by transparent conductors imbedded between the laminations of the windshields. AC electrical power heats the windshields, while control of the system is through the use of DC electrical power which incorporates circuit breakers for system protection. Two switches located on the upper console, one for the pilot and one for the copilot, turn the windshield anti-ice system on and off. Power to operate windshield anti-ice system is provided by the No. 1 and No. 2 AC primary buses through circuit breakers marked PILOT WSHLD ANTI-ICE and COPILOT WSHLD ANTI-ICE, respectively. Two temperature sensors, embedded diagonally across the windshield from each other, provide an input to a controller which maintains the windshield surface temperature at approximately 43°C. Additional system protection is provided by a windshield anti-ice system fault-monitoring circuit that prevents windshield burnout. In the event the monitor circuit turns the windshield anti-ice off, the system may be reactivated by cycling the appropriate windshield anti-ice switch. The windshield anti-ice system is fully operational if the auxiliary power unit (APU) generator is the sole source of AC electrical power, except when the backup hydraulic pump is ON, at which time the windshield anti-ice system is automatically disconnected.

Pitot-Static Anti-Ice

8. Anti-icing of the pilot's and copilot's pitot-static tubes and support struts is accomplished electrically. AC electric power for the pitot heaters is supplied by the No. 1 and No. 2 AC primary buses through the LEFT PITOT HEAT and RIGHT PITOT HEAT circuit breakers to the copilot's and pilot's pitot-static tubes respectively. DC power to the current sensors is provided by the No. 1 DC primary bus through the No. 1 ENG ANTI-ICE circuit breaker. When a low heat or no heat condition is sensed by the current sensor, the RT or LFT PITOT HEAT caution capsules are illuminated on the caution/advisory panel.

DEICE SYSTEM

General

9. The UH-60A main and tail rotor blade deice system (fig 1) uses the cyclic electrothermal deicing concept. A prescribed amount of ice is allowed to accrete on the blade surface. Sufficient heat is applied to the surface to break the ice bond, permitting the ice to be shed by centrifugal force and scavenged away by the airflow. The blade deice system components as shown in schematic form in fig. 2 were: a Rosemount outside air temperature (OAT) sensor (PN 70550-01123-101); a

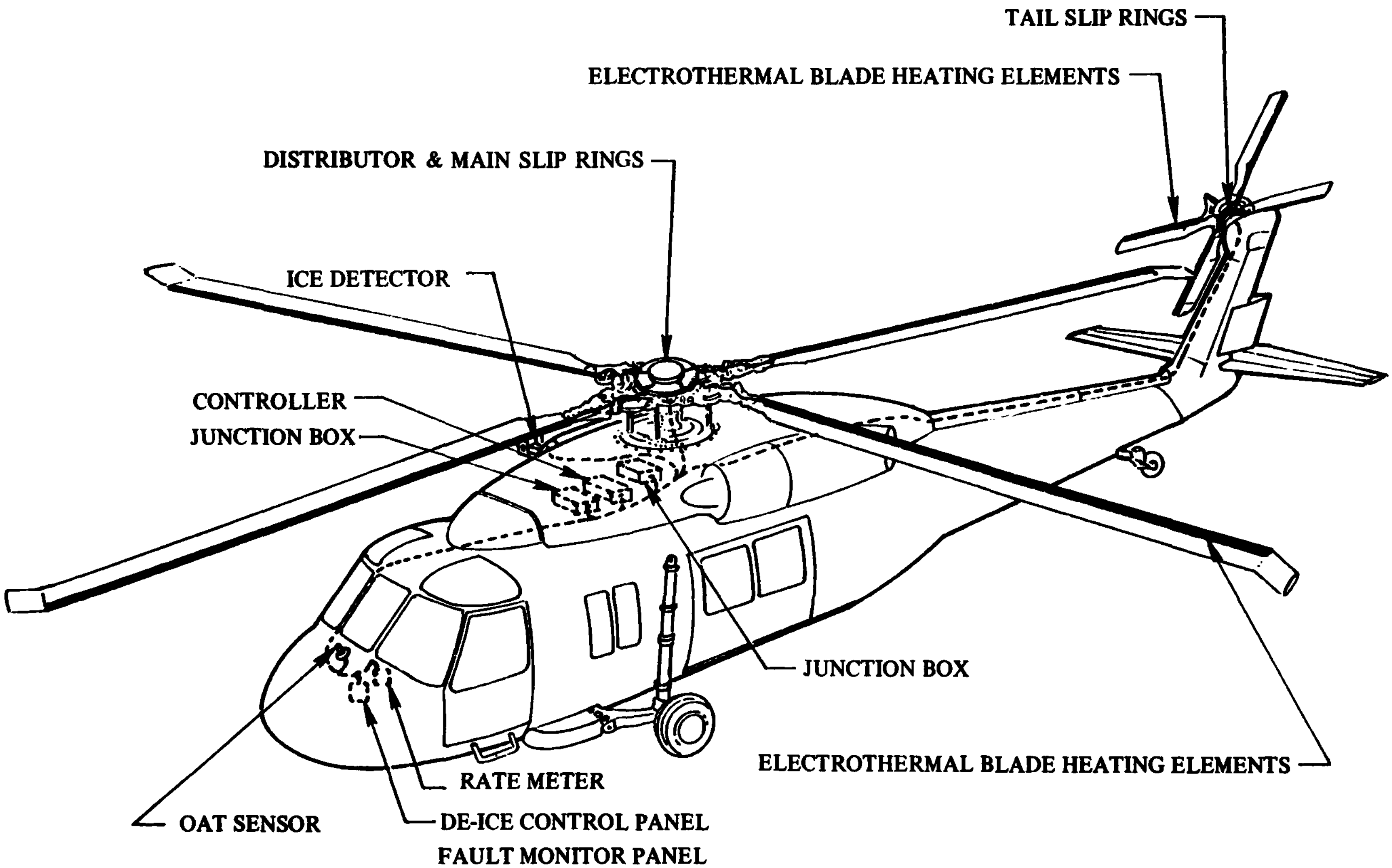

Figure 1. Rotor Blade De-ice

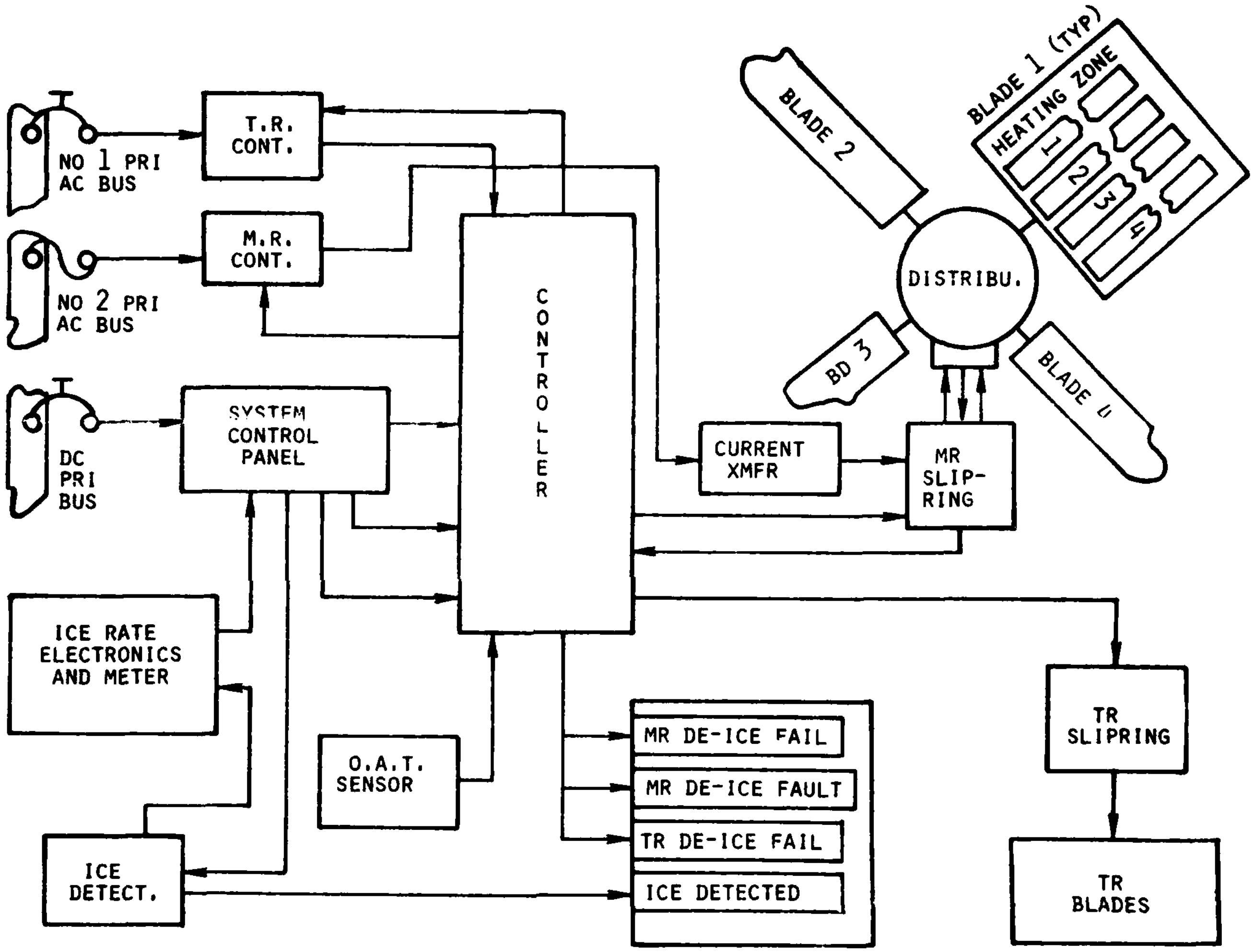

Figure 2. UH-60A Rotor De-ice System

Rosemount ice detector (Model 871FF1, PN 70302-10915-101) mounted on the right engine nacelle; an icing rate meter (PN 70550-01124-101) blade deice control panel (PN 70902-01099-041), and a fault monitor panel (PN X7006-80055-042) mounted on the instrument panel. The system also includes a main and tail rotor slip ring (PN 70500-02128-041 and PN 70550-02129-042 respectively) mounted on the main and tail rotor respectively, a blade deice controller (PN 70550-02126-104), and a main rotor distributor (PN 70550-02127-101). The tail rotor slip ring was slightly modified by enlarging the inner diameter by 0.003 inches due to an interference fit with the older model tail rotor gearbox installed.The main and tail rotor blades contained resistive heating mats.

10. The OAT sensor provided a signal to the deice controller to set heater element on times. The ice detector provides a signal to the ICE DETECTED capsule on the caution/advisory panel and a second signal to the icing rate meter. In the AUTO mode, the icing rate meter provides a signal through the blade deice control panel to the deice controller to set heater element off times. The deice controller provides the blade element electrical heating power through the tail rotor slip rings to the tail rotor blade's heating elements and through the main rotor slip rings and distributor to the main rotor blade's heating elements.

Outside Air Temperature Sensor

11. The OAT sensor was mounted on the nose section between the center windshield and the nose avionics door. A shield was installed in front of the sensor to assist in eliminating kinetic heating effects. The OAT sensor supplied a signal to the blade deice controller to set element on time between 1 and 13 seconds for the eight main rotor deice pulses and between 1 and 32 seconds for the one tail rotor pulse (fig 3, app F).

Ice Detectors

12. One magnetostrictive, aspirated Rosemount ice detector was mounted on the right engine nacelle. When the BLADE DEICE control panel POWER switch is placed ON, 28 vdc is supplied from the DEICE CNTRLR circuit breaker to the icing rate meter where it controls the circuit used to heat the aspirated portion of the ice detector. The aspirator is provided to assure ice detection at a hover and consists of engine compressor discharge air passing over an ice detector inlet, causing ambient air to pass over the detector probe. The detector provides two output signals, one to the ICE DETECTED capsule on the caution/advisory panel and one to the icing rate meter.

Icing Rate Meter

13. The icing rate meter was located on the right center of the instrument panel (fig. 3). The icing rate meter provides a signal to the deice controller through the AUTO position of the MODE SELECT switch on the BLADE DEICE control panel. The signal is used to control element off time. The more severe the rate of icing the shorter the element off time. Element off time varies from 240 seconds for trace icing to 60 seconds for moderate icing for the main rotor blades and from 80 seconds for trace icing to 20 seconds for moderate icing for the tail rotor blades. The icing rate meter contains a hold circuit to hold the last icing signal from the ice detector during the time the heating current is supplied to the ice detector. The icing rate meter contains built in test circuitry and fault monitoring circuitry. The test is

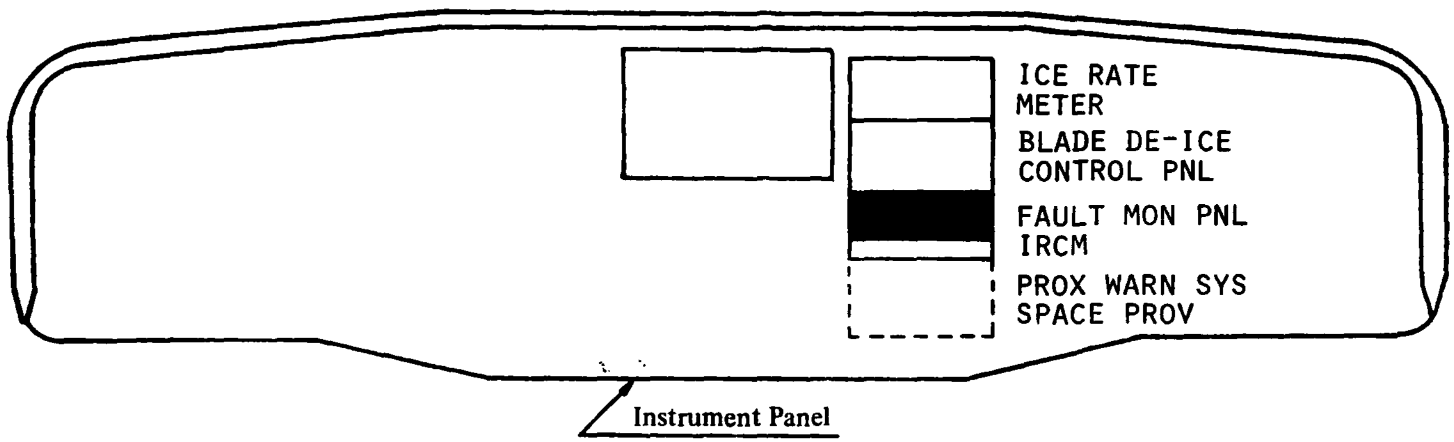

Figure 3. Icing Rate Meter Location

activated by depressing the test button on the meter. The test conducts a calibration check on the rate meter electronics and checks power application to the ice detector probe heater. Failure to pass this test is indicated by the appearance of the fail flag. The icing rate meter was modified by the manufacturer during the testing by application of a 4 second holding circuit in the under and over frequency monitoring circuits.

Blade Deice Control Panel

14. The blade deice control panel located on the right center of the instrument panel contains the controls necessary to operate the deice system. The control panel provides power to the controller through the POWER ON-OFF-TEST switch and an icing rate signal to the controller either through the AUTO or MANUAL positions of the MODE SELECT switch. Provisions are included for self-test. The pilot exercises his option to select either automatic or manual off time control of the system. Placing the MODE SELECT switch in AUTO results in an icing rate signal from the rate meter to the controller, regulating off times according to icing intensity. Selection of manual mode of operation by placing the MODE SELECT switch in one of three manual positions replaces the icing rate signal with one of three preset signals corresponding to trace (T), light (L) or moderate (M) icing. The manual mode of operation requires the pilot's assessment of icing intensity, and should only be used if the pilot suspects the icing rate system is malfunctioning. It is important to note that the MODE SELECT switch has no effect on heater on times. The heater element on time (i.e., the period of power application to each rotor blade heating zone) is controlled by the system controller and an outside ambient temperature sensor. The self-test is initiated by placing the POWER switch to TEST. The controller overrides existing element on and off times to execute a test program. The program consists of a 100 second off time followed by approximately 0.5 second element on time applied to the main and tail rotor blade heating elements. The test in progress lamp illuminates during the test and extinguishes when the test is complete. Failure of the test is indicated by illumination of either TR DEICE FAIL or MR DEICE FAIL caution capsules.

Deice Controller

15. The deice controller was located in the cabin overhead. Operating voltage for the controller was supplied through the DEICE CNTRLR circuit breaker located on the mission readiness circuit breaker panel. The main and tail rotor control circuit closes the main rotor contactor and produces a pulse train (fig 4) consisting of eight pulses followed by a waiting period, or off time. The counter always resets to zero; that is, the controller always produces a complete train of eight pulses when operation is initiated or when input power is restored after an interruption. The pulse trian is supplied to the control input of the main rotor power distributor through the main rotor slip ring assembly. The same slip ring assembly carries power to the distributor. In response, the distributor supplies power in proper sequence to the rotor blade heating elements (fig 3). Eight gating pulses are required, since the main rotor blades, each with four independent heating zones, are deiced in pairs. The first gating pulse causes power to be applied to output 1 (zone 1 of blades No. 1 and No. 3); . . and so on through the sequence of eight pulses. The sequence counter always resets to output 1 after the off time has elapsed or if there is an interruption of power. The tail rotor control circuit provides an output to the tail rotor contactor coil. Energizing the contactor applies power via the tail rotor slip ring assembly simultaneously to all the heating elements of the tail rotor therefore a distributor is

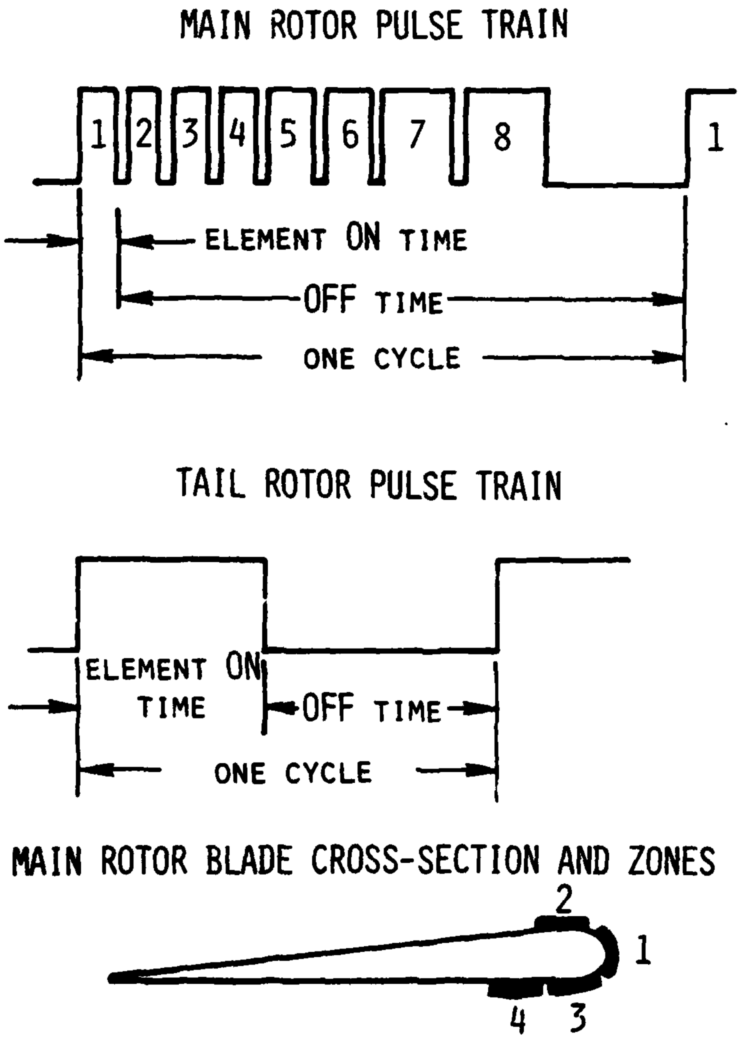

Figure 4. Blade De-ice System

not required. The control circuit responds to the OAT sensor to determine the on time of the tail rotor heating elements. The monitor circuits in the controller continuously check the operation of the system. Three-phase current transformers on the main and tail power leads provide signals corresponding to the actual current delivered to the heaters. By comparing the current delivered with the controller's pulse train, and checking for magnitude balance of the three individual phase currents, the monitor circuits detect such malfunctions as an open circuit heater phase or feeder wire, zero output during a gating pulse, or a short-circuit heater phase. The monitor circuits also detect OAT sensor failure (open- or short-circuit) and an incomplete or improper output pulse train from the controller. Cockpit indicators inform the crew of system fault or failure.

Main and Tail Rotor Blade Heating Elements

16. The main rotor blade heating elements are embedded in the leading edge sheath and cover 21 to 92 percent spanwise and 12 percent upper to 17 percent lower surface chordwise. These elements are divided chordwise into four independent electrical heating zones. Tail rotor blade heating elements are embedded in the leading edge from 25 to 91 percent spanwise and 12 percent upper and lower surface chordwise. These elements are single electrical heating zones.

Fault Monitor Panel

17. The preproduction fault monitor panel was located on the right center of the instrument panel. The panel served to check the deice system for failures that are otherwise dormant during the normal TEST cycles. The panel accomplishes this by introducing selected failure signals into the system and requiring the deice controller built-in monitor circuitry to function in a specific manner. The fault monitor check is performed as part of the deice system ground check. In the NORM position, the fault monitor allows system test to be performed without the introduction of false failure signals. Thus, the system should complete its self check-out cycle without failure legends being illuminated on the caution panel. In the SYNC 1 and SYNC 2 positions, the fault monitor interrupts the distributor sync line and provides the controller with a false sync input. The controller must interpret these false signals as indications of distributor failure, and produce a MR DEICE FAIL caution light for both cases. The fault monitor provides the controller with a -30 vdc signal when SYNC 1 is selected, and an open circuit signal when SYNC 2 is selected. In the OAT position, the fault monitor "short-circuits" the OAT sensor. Built-in test equipment (BITE) circuitry within the controller must sense the simulated failure and illuminate both the MR DEICE FAIL and TR DEICE FAIL caution lights. In the element on time (EOT) position, the fault monitor biases both BITE circuitry in the controller and the OAT sensor to simulate defective primary EOT timing circuits. The biased BITE circuit is thus deceived into believing that the primary circuits are in error. The controller must illuminate both the MR DEICE FAIL and the TR DEICE FAIL lights when this occurs. The fault monitor also functions automatically during in-flight system use to sense contradictory signals from the deice power circuits. If electric power remains applied to either the main or tail rotor heating elements after the controller signals a FAIL condition or when the system is off, then the fault monitor illuminates the respective PWR light on its front panel. The light informs the crew that further action is required to isolate the deice loads indicated.

APPENDIX C. HELICOPTER ICING SPRAY SYSTEM (HISS) DESCRIPTION

The HISS is installed in a modified CH-47C helicopter and consists of an internally mounted 1800-gallon water tank and an external spray boom assembly suspended 19 ft beneath the aircraft from a cross-tube through the cargo compartment. A schematic is shown in figure 1, and a detailed description is given in reference 1. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external boom assembly and water supply can be jettisoned in an emergency. The spray boom consists of two 27-ft center sections, vertically separated by 5 ft, and two 17.6-ft outriggers. The outriggers are swept back 20 degrees and angled downward 10 degrees giving a tip to tip boom width of 60 ft. A total of 97 Sonic Development Corp. Sonicore model 125-HB nozzles are installed on the two center sections. The spray cloud is generated by pumping water at known flow rates from the tank to the nozzles on the boom assembly, using aircraft engine compressor bleed air to atomize the water.

A calibrated outside air temperature probe and a dew point hygrometer provide accurate temperature and humidity measurement. An aft-facing radar altimeter is mounted at the rear of the HISS to allow positioning the test aircraft at a known standoff distance. Because of gross weight and center of gravity limitations, the aft fuel cells of the helicopter are left empty and only 1500 gallons of water are carried. For icing tests, a chemical with coloration properties similar to sea marker dye is added to the water and imparts a yellow color to the ice.

At the 150 to 250 ft standoff distances used for icing tests, the size of the visible spray cloud is 8 ft deep and 36 ft wide. The measured drop size distribution and liquid water content (LWC) variation of the spray cloud are in figures 2 and 3 (ref 2). For a 90 KTAS test condition, the average LWC of the spray cloud was controlled by adjusting the water flow rate as shown in figure 4. This relation was theoretically derived assuming mass conservation (no evaporation) and a uniform water distribution over the cloud cross-sectional area (288 ft^2). However, this line also provides a close fit to averaged LWC data measured in flight at relative humidity conditions above 65% and temperatures below -5°C.

References:

1. Handbook, SM-280B, *Installation, Operation, and Maintenance Instructions with List of Parts, Helicopter Icing Spray System (HISS)*, All American Engineering Co., with Change 1, Nov 74.

2. Report, Meteorology Research, Inc., No. MRI 80 dFR-1748, *Droplet Size and Liquid Water Characteristics of the USAAEFA (CH-47) Helicopter Spray System and Natural Clouds as Sampled by a JUH-1H Helicopter*, Apr 80.

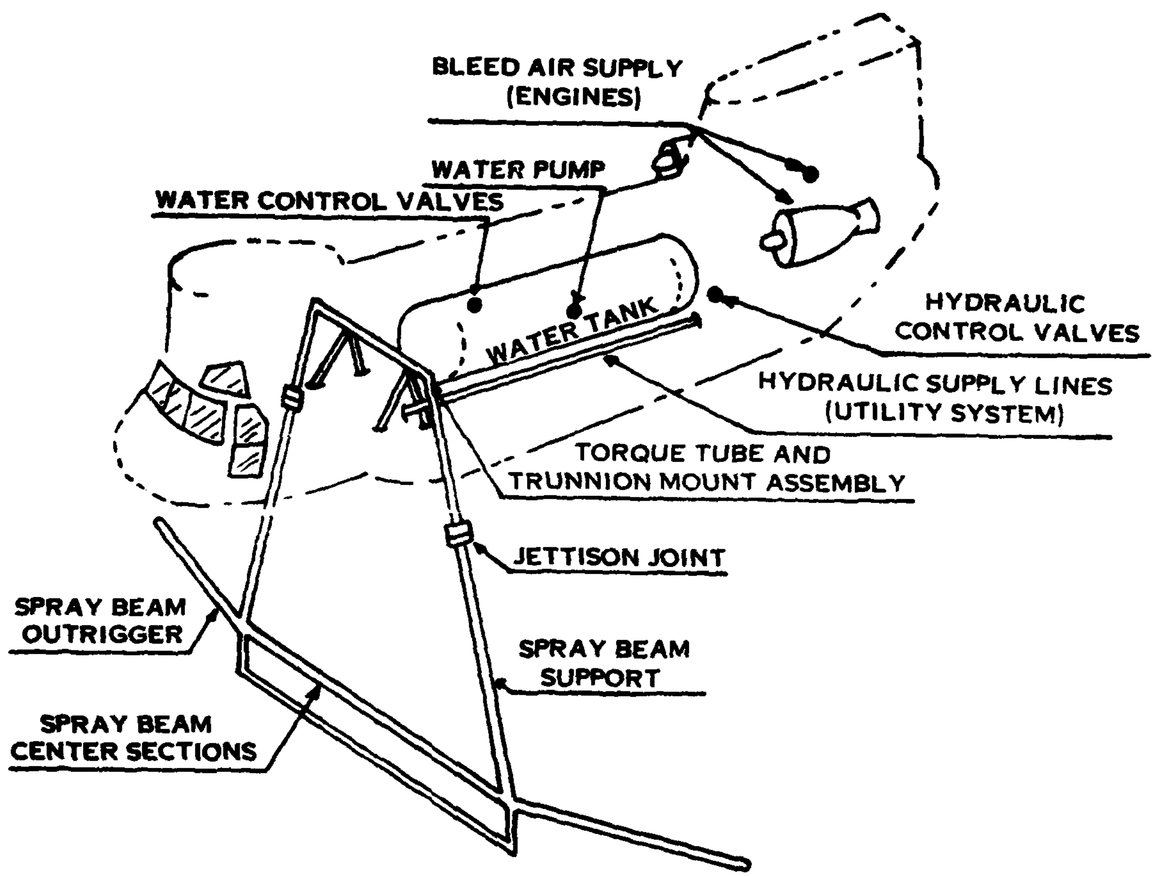

Figure 1. HISS Schematic

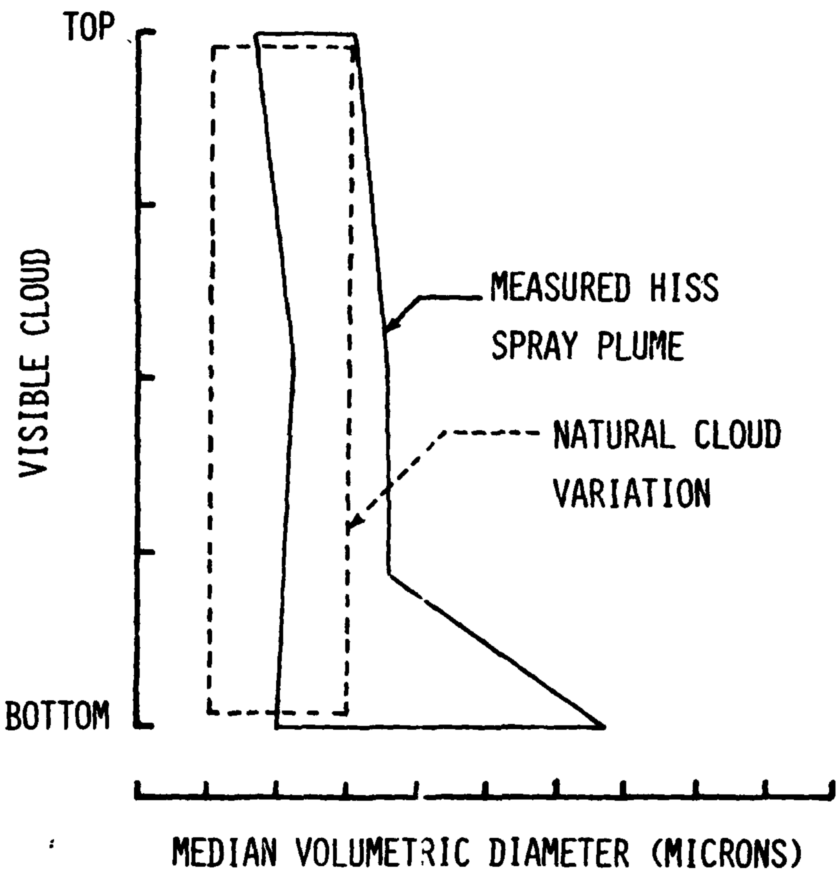

Figure 2. Vertical Variation of Cloud Droplet MVD

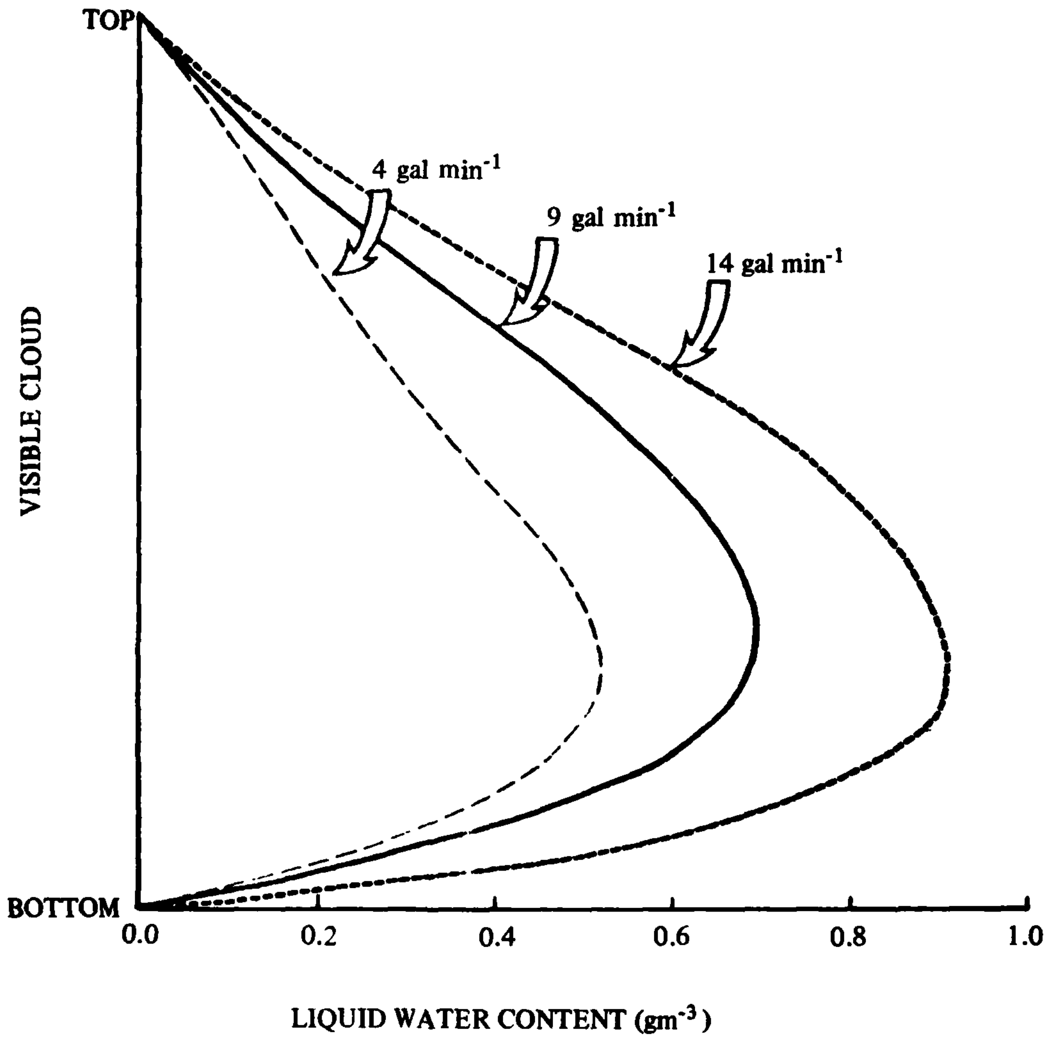

Figure 3. Vertical Variation of Visible Liquid Water Content

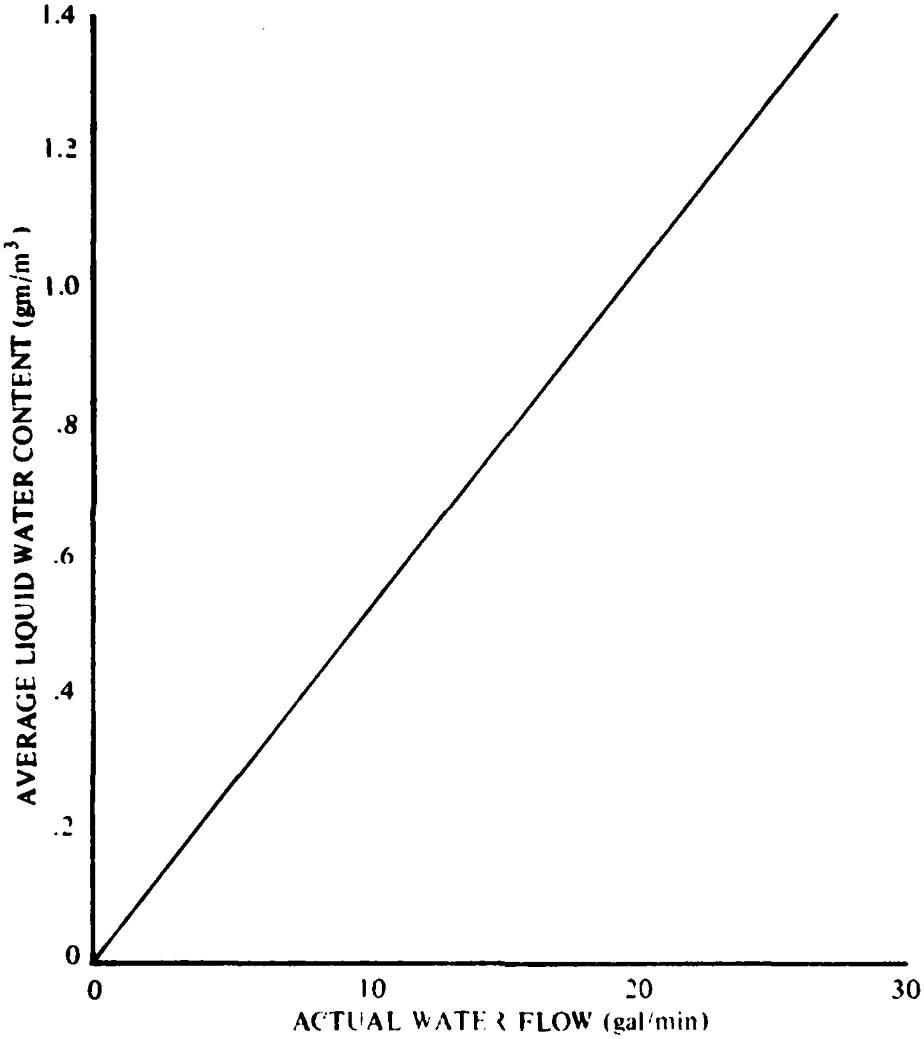

Figure 4. HISS Water Flow vs. Icing Cloud LWC

APPENDIX D. INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA personnel. Data were measured with calibrated instumentation and displayed or recorded as indicated below. Test instrumentation installation is shown in photos 1 through 6.

<u>Pilot's Panel</u>

Liquid water content (Rosemount Probe)

<u>Copilot Panel</u>

Airspeed (ship's system)
Pressure altitude (ship's system)

<u>Engineer Panel (photos 3)</u>

Instrumentation controls
Free air temperature
Time code display
Run number
Fuel flow rate
Fuel used
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Stabilator position

<u>Digital (PCM) Data Parameters</u>

Airspeed (ship's system)
Altitude (ship's system)
Total air temperature
Rotor speed
Gas generator speed**
Fuel used**
Engine fuel flow**
Engine output shaft torque**
Engine measured gas temperature**
Control position:
- Longitudinal cyclic
- Lateral cyclic
- Directional
- Collective

Stability augmentation position:
- Longitudinal
- Lateral
- Directional

Stabilator angle of incidence
Aircraft attitude:
- Pitch

Roll
Yaw
Aircraft angular velocity
  Pitch
  Roll
  Yaw
Engine inlet surface temperature** (photo 4)
Customer bleed air pressure**
Engine anti-ice valve position**
Engine inlet duct anti-ice valve position**
Generator (No. 1, No. 2, and APU):
  Voltage (A phase)
  Current (A phase)
Deice/anti-ice system electrical parameters:
  Main rotor voltage (A phase)
  Main rotor current (A phase)
  Tail rotor voltage (A phase)
  Tail rotor current (A phase)
  Windshield voltage (A phase)
  Windshield current (A phase)
Rosemount icing rate
Time of day
Run number
Pilot and engineer event pulse
**Both engines

Analog (FM) Data Parameters

Vibration (accelerometers)
  Pilot station vertical
  Pilot station lateral
  Pilot station longitudinal
  Copilot station lateral
  Aircraft cg vertical
  Aircraft cg lateral
  Aircraft cg longitudinal
  Main transmission (top) vertical
  Main transmission (top) lateral
  Main transmission (top) longitudinal
  Tail rotor gearbox vertical
  Tail rotor gearbox lateral
  Tail rotor gearbox longitudinal
  Right transmission support beam vertical
  Right transmission support beam lateral
  Right transmission support beam longitudinal
  Left transmission support beam vertical
  Left transmission support beam lateral
  Left transmission support beam longitudinal
  Right stabilator tip vertical
  Right stabilator tip longitudinal
  Left stabilator tip vertical
  Left stabilator tip longitudinal

Vibration (velocity):
Exhaust frame vertical (both engines)
Exhaust frame longitudinal (both engines)
Main rotor longitudinal star load

Airspeed Calibration

2. The airspeed system position error contained in the Safety of Flight Release (ref 8, app A) was used to determine calibrated airspeed.

SPECIAL EQUIPMENT

Camera Systems

3. One Canon 16mm camera system was installed on the test aircraft to photograph the tail rotor and horizontal stabilator in flight. The camera film magazine held 100 ft of film and camera shutter speeds of up to 64 frames per second (fps) were available. Another 16mm high-speed hand-held motion picture camera was located on board the chase aircraft and was used to document the test aircraft both in the spray cloud and after exit from icing encounters. Additionally, 35mm color slide and black and white still cameras were used for documentation both in the air and on the ground following icing flight.

4. The tail camera was mounted on the right side of the tail cone facing aft toward the tail rotor (photo 5). The camera installation was covered with a fairing to prevent ice buildup. A shutter speed of 64 fps was used.

Visual Ice Accretion Probe

5. A visual ice accretion indicator probe was fabricated and installed on the test aircraft. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe was composed of a small symmetrical airfoil section (OH-6A tail rotor blade sections) with 3/16-inch diameter steel rod protruding outward from the leading edge at the center span. The protruding rod was painted with 1/4-inch stripes of contrasting colors which provided a comparison basis for visual ice measurements. The probe was mounted on the left cockpit door just below the window. Photo 6 shows the installation of the visual ice accretion probe.

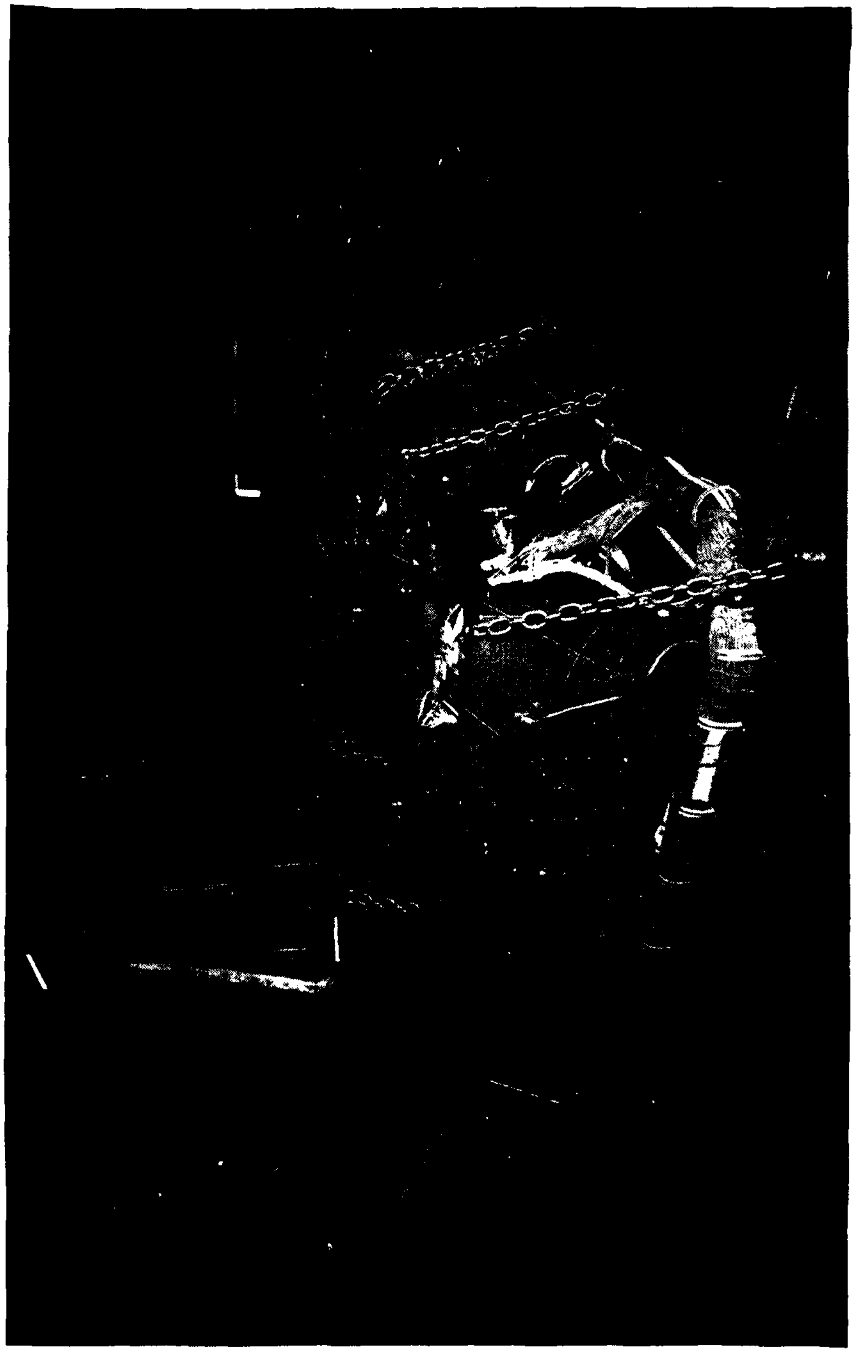

Photo 1. Instrumentation Package Installation

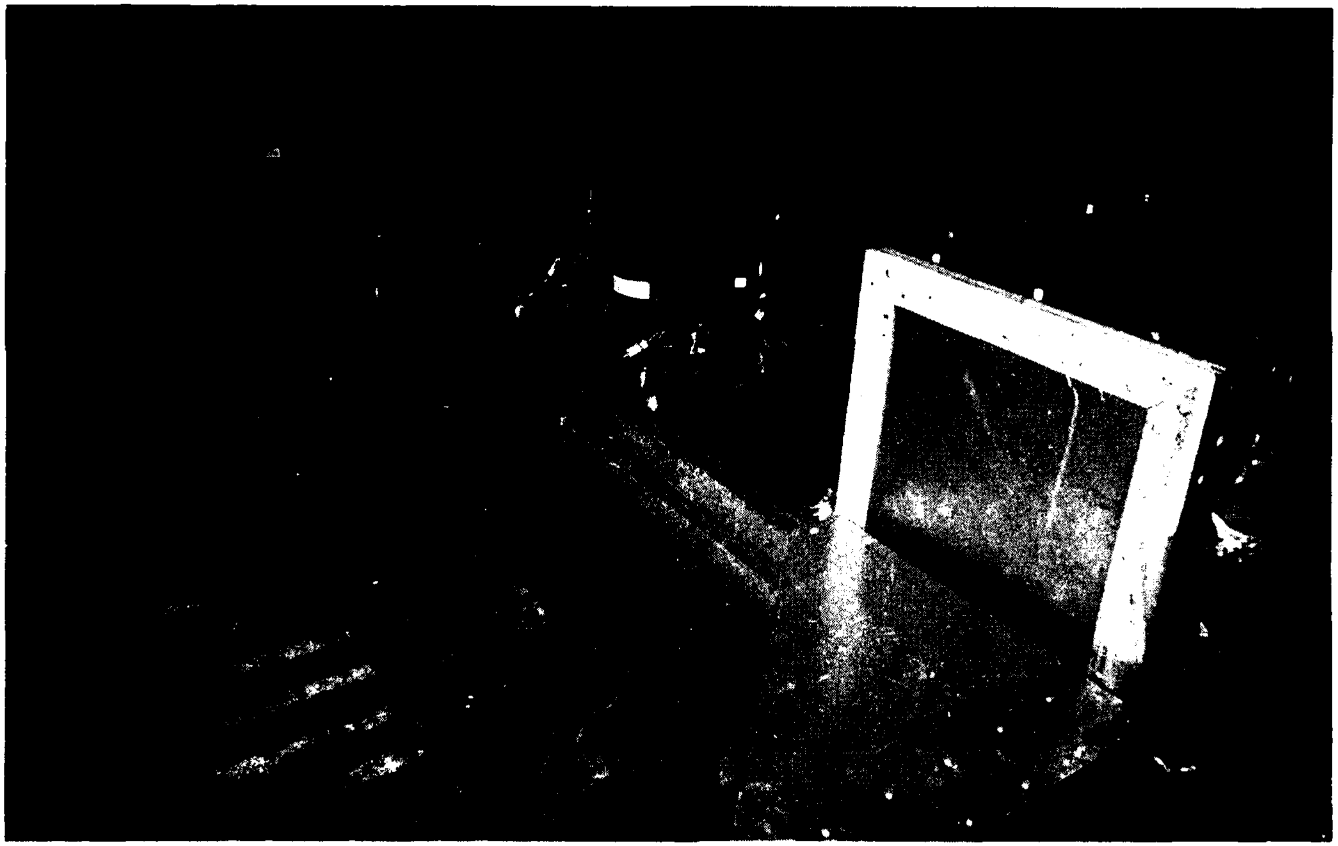

Photo 2. Instrumentation Gyro and Ballast Box Installation

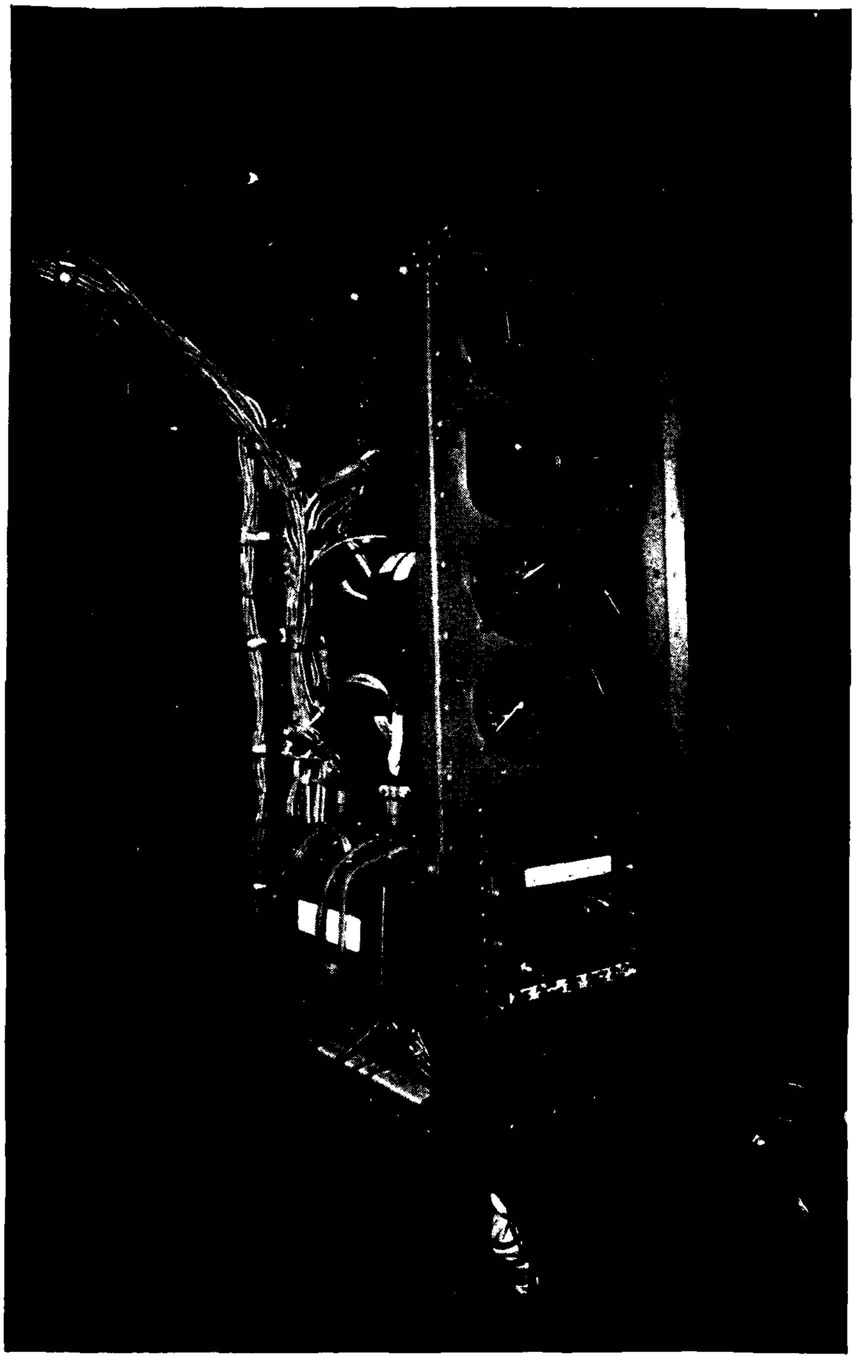

Photo 3. Engineer's Panel

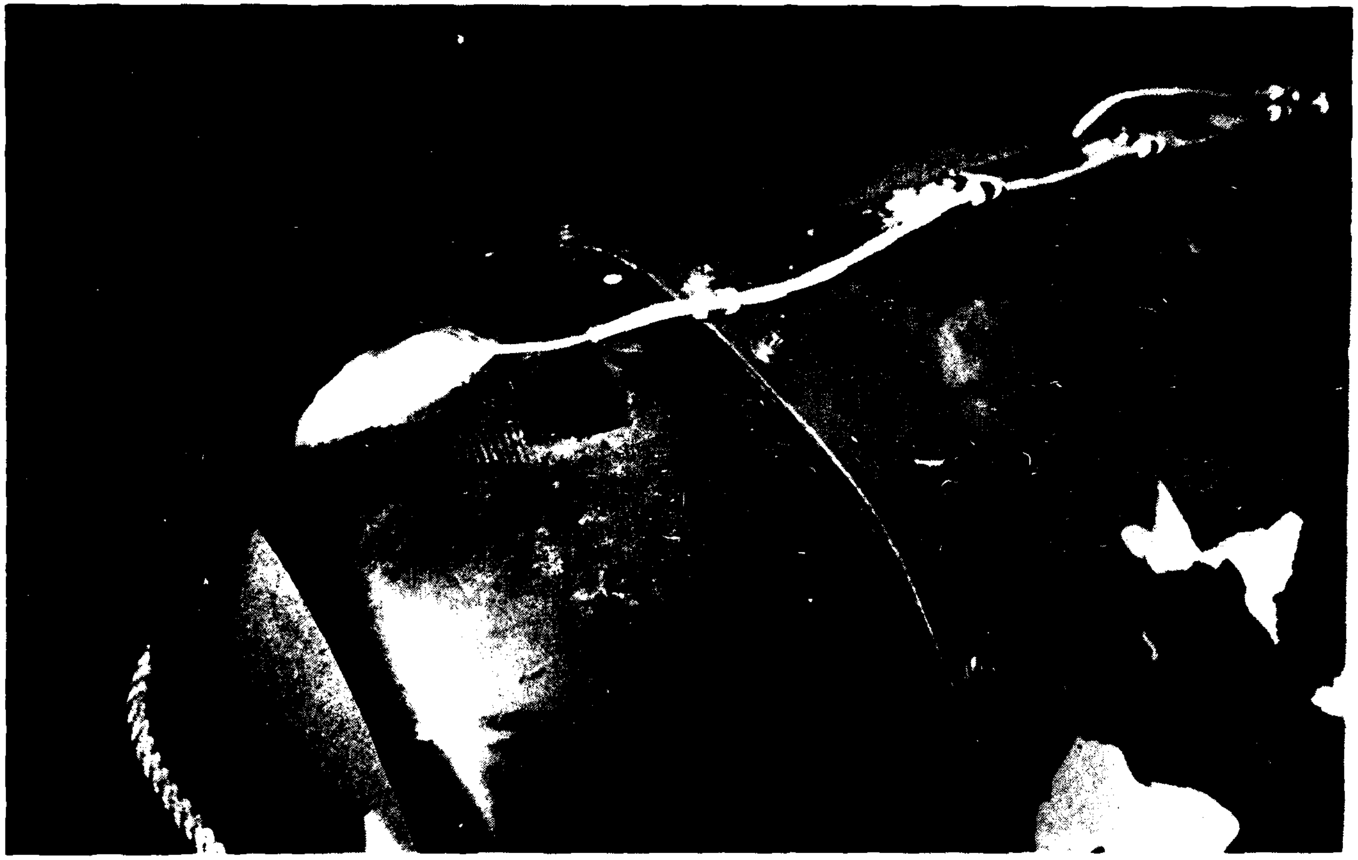

Photo 4. Inlet Surface Temperature Location

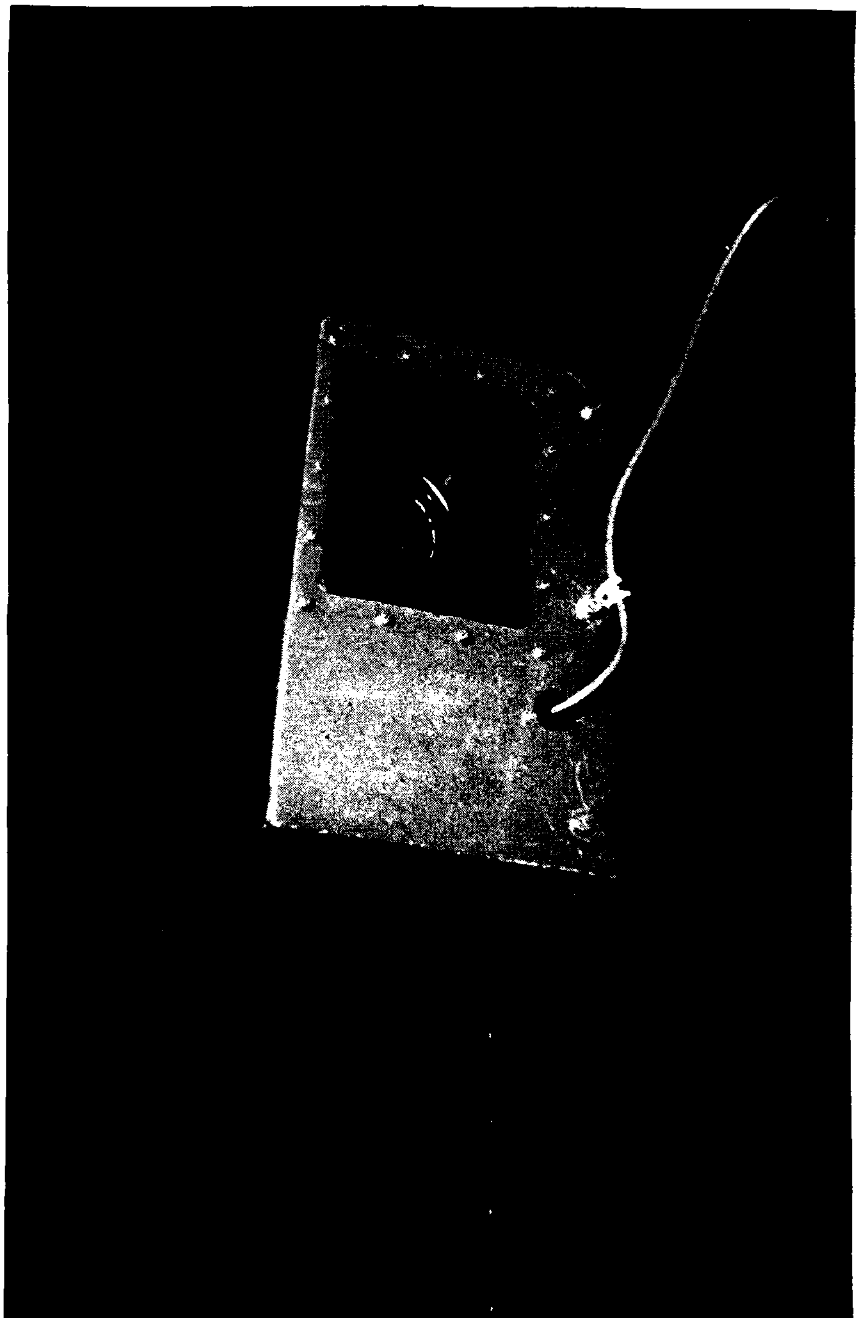

Photo 5. External Camera Installation

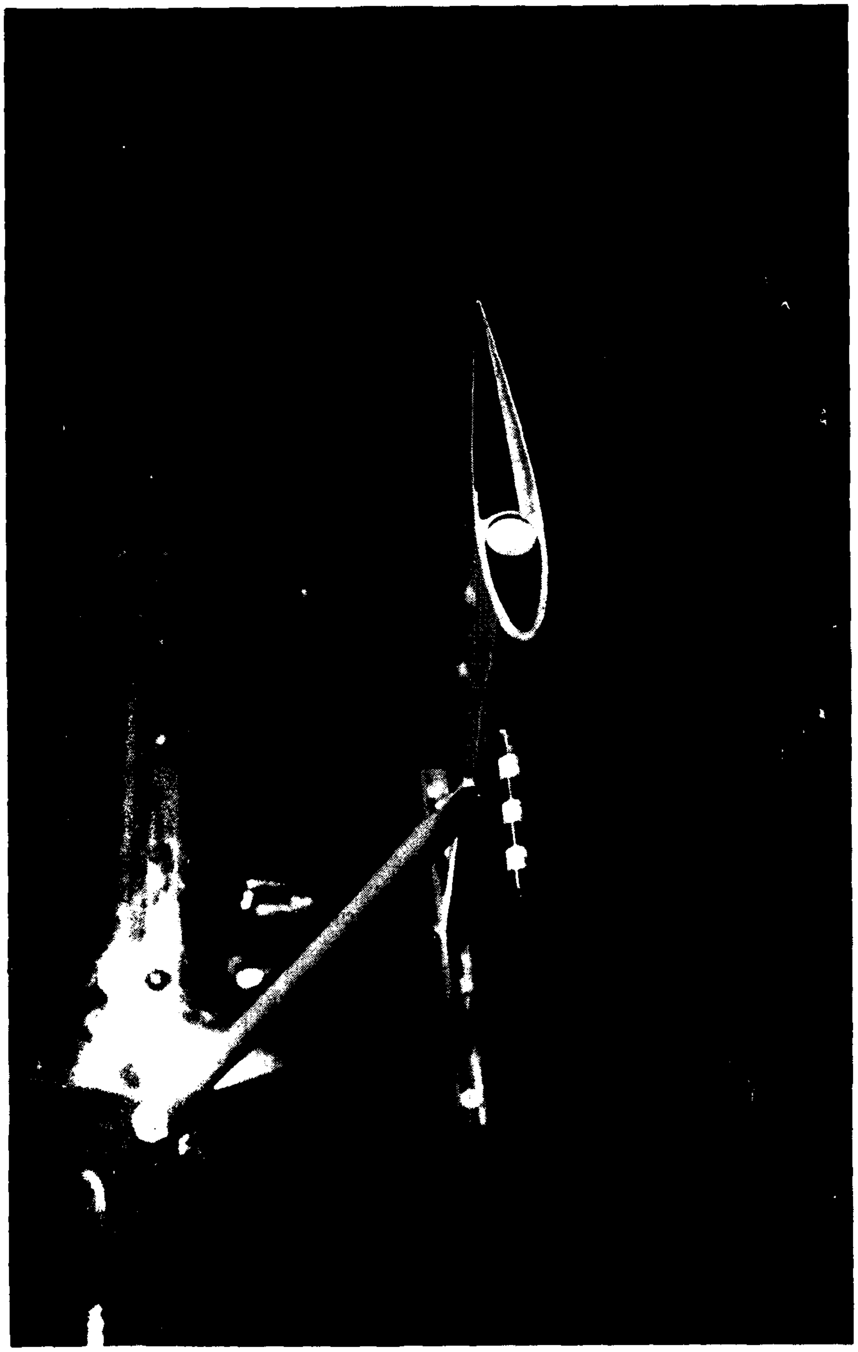

Photo 6. Visual Ice Accretion Probe

APPENDIX E. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. The deice system tested on the UH-60A was a production system. A build-up program was used to gain experience with flight in icing conditions. The procedure remained the same for each flight up to entry into the cloud. All anti-ice systems (*ie*, pitot heat, windshield anti-ice, engine, and engine air induction system anti-ice) were activated while enroute to the test area. After reaching the test altitude, base-line autorotation and level flight performance data were obtained. The test aircraft then entered the artificial spray cloud from a position below and approximately 200 feet behind the spray aircraft. Test and spray aircraft separation distance was maintained during the icing flight by information relayed from the spray aircraft. The magnetic tape recording system was activated periodically during natural and artificial cloud encounters. During artificial tests, airspeed and outside air temperature (OAT), while in the cloud, were established with the calibrated airspeed system of the spray aircraft. All artificial flights were flown with a predetermined LWC and OAT. Flight continued in the cloud condition until a test aircraft limitation (*ie*, power, system failure, fuel, etc) was reached. Vibration and performance parameters were monitored continuously during each flight. After the test aircraft exited the cloud, level flight and autorotation data were recorded and the aircraft then returned to the landing area.

2. A progressive build-up procedure was used during the flight testing. The approach was to start at the lowest LWC and warmest temperature and incrementally increase LWC and decrease temperature. As confidence was gained in the deice system and the aircraft's ability to cope with the icing environment, the requirement for flights of limited duration was eliminated and long immersion flights in the icing environment were conducted.

ICE ACCRETION AND SHEDDING

3. Ice accretion was determined in flight using the visual ice accretion probe indicator. The visual probe was monitored by the copilot during flight in the cloud. The Rosemount icing rate meter was used to monitor LWC.

4. Ice accretion was documented using a motion picture camera mounted on the test aircraft and hand-held, high-speed motion picture cameras photographing from both the chase aircraft and the spray aircraft. Postflight photographs were made to document the ice remaining on the individual components of the airframe and rotors.

5. The icing severity was a function of time in the spray cloud, temperature, and LWC. The programmed icing severity was compared with the Rosemount detector. Ice accretion was measured in flight using the visual probe and high-speed photography. When practical, postflight ice accretions were measured immediately upon landing.

6. Ice shedding characteristics were qualitatively assessed by crew members in the test, spray, and chase aircraft. In addition to the high-speed motion pictures taken from the chase and spray aircraft, a camera was mounted viewing the tail rotor and stabilator of the test aircraft. A description of the test aircraft camera is presented in Appendix D.

PERFORMANCE

Level Flight Performance

7. Level flight performance data were obtained by establishing trim level flight at the test airspeed, altitude, and OAT, using the test aircraft calibrated instruments. Data were recorded before, during, and again after icing was completed. Several trim true airspeeds were used throughout the flight testing.

8. Level flight performance degradation due to ice accretion was assessed by comparing the engine power required to maintain constant airspeed and altitude during ice accumulation. Shaft horsepower was calculated using equation 1.

$$SHP = N_R \times Q \times K \times \frac{2\pi}{33,000} \qquad (1)$$

Where:

SHP = Calculated shaft horsepower (shp)

N_R = Main rotor rotational speed (rev/min)

Q = Engine output shaft torque (ft-lb)

K = Gearing constant between engine and main rotor (76.05)

Engine Performance

9. Engine and engine inlet anti-ice system performance ıta were obtained in conjunction with the icing flights. The test aircraft was stabi..zed in trimmed level flight at the various test altitudes and temperatures. Testing was conducted with all anti-ice systems OFF for base-line data, then with all anti-ice systems ON. The cabin heater was turned on and the temperature controller was set to maximum on some test conditions.

10. The engine power required to operate the anti-ice/deice systems was also determined by measuring engine performance at various test conditions. Data on SHP, measured gas temperature ($T_{4.5}$), fuel flow (W_f), and gas generator speed (N_G) were referred as follows.

a. Referred SHP (RSHP):

$$RSHP = SHP/\delta_1\sqrt{\theta_1} \qquad (2)$$

b. Referred gas temperature (RGAST):

$$RGAST = \frac{T_{4.5} + 273.15}{(\theta_1)^{0.96}} - 273.15\ (^\circ C) \qquad (3)$$

c. Referred fuel flow (RWF):

$$RWF = \frac{W_f}{(\delta_1)(\theta_1)^{0.50}} \text{ (lb/hr)} \quad (4)$$

d. Referred gas generator speed (RN_G):

$$RN_G = \frac{N_G}{(\theta_1)^{0.50}} \quad (\%) \quad (5)$$

Where:

$$\delta = \left[1 - (6.875586 \times 10^{-6})(H_p)\right]^{5.25585}$$

H_p = Test pressure altitude (ft)

$$\theta_1 = \frac{OAT_{static} + 273.15}{288.15}$$

OAT_{static} = Test Static air temperature (°C)

$T_{4.5}$ = Turbine inlet temperature (°C)

W_f = Engine fuel flow (lb/hr)

N_G = Gas producer speed referenced to 44,700 RPM (percent)

Autorotational Descent Performance

11. Autorotational descent performance data at the recommended airspeed for minimum rate of descent, were obtained on those flights designated as long immersion flights. Base-line autorotational descent data were recorded near the test altitude with no ice accumulation on the test aircraft to verify the data contained in the operator's manual. After icing the aircraft autorotational descent data were recorded and compared with the data in the operator's manual. Changes in vertical rates of descent, collective control position, and stabilized autorotational rotor speed were noted.

HANDLING QUALITIES

12. The effect of ice accretion on the test aircraft handling qualities was qualitatively assessed by the pilot. Control positions were quantitatively measured and comparisons made between no-ice base-line data and data recorded after ice accretion.

VIBRATION

13. Vibration levels were qualitatively assessed during each flight. An FM magnetic tape recorder was used to quantify the vibration data. Data obtained from the

magnetic tape system were analyzed using a Spectral Dynamics 301 spectral analyzer. The spectral analyzer was used to convert the data from the time domain (acceleration or velocity as a function of time) to the frequency domain (acceleration or velocity as a function of frequency). The Vibration Rating Scale, presented in figure 1, was used to augment crew comments on aircraft vibration levels.

WEIGHT AND BALANCE

14. Prior to testing, the aircraft gross weight, longitudinal and lateral cg were determined by using calibrated scales. The longitudinal cg was calculated by a summation of moments about a reference datum line (FS 0.0). The aircraft was weighed empty, which included instrumentation minus fuel.

DEFINITIONS

15. Icing characteristics were described using the following definitions of icing types and severity.

a. Icing type definitions:

(1) Rime ice: An opaque granular deposit of ice formed by the rapid freezing of small supercooled water droplets.

(2) Clear ice: A semitransparent smooth deposit of ice formed by the slower freezing of larger supercooled water droplets.

(3) Glime ice: A mixture of clear ice and rime ice.

b. Icing severity definitions:

(1) Trace icing: Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though deicing equipment is not used, unless encountered for an extended period of time (over 1 hour).

(2) Light icing: The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.

(3) Moderate icing: The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.

(4) Severe icing: The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

16. Results were categorized as deficiencies or shortcomings in accordance with the following definitions (ref 14, app A):

<u>Deficiency</u>: A defect or malfunction discovered during the life cycle of an equipment that constitutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued; indicates improper design

DEGREE OF VIBRATION	DESCRIPTION[1]	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1, 2, 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4, 5, 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7, 8, 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level.	10

[1] Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Figure 1. Vibration Rating Scale

or other cause of an item or part, which seriously impairs the equipment's operational capability. A deficiency normally disables or immobilizes the equipment; and if occurring during test phases, will serve as a bar to type classification action.

Shortcoming: An imperfection or malfunction occurring during the life cycle of equipment, which should be reported and which must be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation, or materially reduce the usability of the material or end product. If occurring during test phases, the shortcoming should be corrected if it can be done without unduly complicating the item or inducing another undesirable characteristic such as increased cost, weight, etc.

APPENDIX F. TEST DATA

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<u>Figure</u>	**<u>Figure Number</u>**
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Natural Icing Test Conditions	2
Blade Deice On Time	3
Blade Deice Off Time	4
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Engine Inlet Surface Temperature Characteristics	11 thru 12
Blade Deice Cycle	13 thru 15
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Engine and Engine Inlet Anti-Ice System Actuation	29 thru 32

Table 1. Specific Test Conditions

Flight Number	Environment	Configuration[1]	Average Gross Weight (lb)	Average Longitudinal CG (FS in.)	Average Density Altitude (ft)	Average OAT (°C)	Average LWC (gm/m³)	Maximum LWC (gm/m³)	Average TAS (KTAS)	Total Time in Cloud (minutes)	Ice Accreted on Visual Probe (in.)
3	Artificial	I.R.	16,480	354.5	-1120	-13.0	0.25 0.50	0.25 0.50	82	30 30	N/A
4	Artificial	I.R.	16,480	354.5	-900	-15.5	0.25 0.50	0.25 0.50	82	30 30	N/A
5	Natural	I.R.	16,760	355.6	2260	-7.0	0.19	0.32	117	30	1.50
6	Natural	I.R.	16,660	355.2	2100	-7.5	0.24	0.46	121	65	1.75
7	Artificial	I.R.	16,640	355.2	-960	-21.5	0.25 0.50	0.25 0.50	82	30 15	N/A
9	Natural	I.R.	16,420	354.3	4080	-12.0	0.09	0.10	120	90	2.25
11	Artificial	I.R.	16,260	353.7	840	-20.0	0.50 0.75 1.00	0.50 0.75 1.00	83	30 15 15	N/A
13	Natural	Clean	16,180	354.1	6880	-5.5	0.05	0.15	124	90	0.60
14	Natural	Clean	16,000	353.4	8260	-7.5	0.07	0.25	128	85	1.13
16	Natural	Clean	16,140	353.9	1420	-5.0	0.01	0.03	119	85	1.00
19	Natural	Clean	16,360	354.7	2160	-11.0	0.06	0.18	121	105	2.50
21	Natural	Clean	16,120	353.8	9500	-10.0	0.03	0.06	115	70	0.62
22	Natural	Clean	16,060	353.5	1760	-5.0	0.09	0.17	125	90	1.25
24	Natural	Clean	16,280	354.4	1380	-4.0	0.32	0.61	126	95	4.00
25	Natural	Clean	16,040	353.4	1740	-5.0	0.20	0.45	137	75	3.50
26	Natural	Clean	16,120	353.8	2920	-7.5	0.24	0.34	113	105	5.00
27	Natural	Clean	16,180	354.0	2880	-7.5	0.13	0.25	138	85	3.00
28	Natural	Clean	16,420	354.9	3180	-7.0	0.07	0.09	93	120	3.50

NOTE: [1] IR Configuration - Infra-Red Suppressors, ALQ-144 Countermeasures Device, M-130 Chaff Dispenser
Clean Configuration - Standard Tailpipe installation, M-130 Chaff Dispenser

FIGURE 1

ARTIFICIAL ICING TEST CONDITIONS

TEMPERATURE °C	LIQUID WATER CONTENT (gm/m^3)			
	0.25	0.5	0.75	1.0
-5		□	□	
-10	●	□ ●		
-15	●	●		
-20	●	●	●/	●/

□ — 1979 Icing season STANDARD TAILPIPE CONFIGURATION

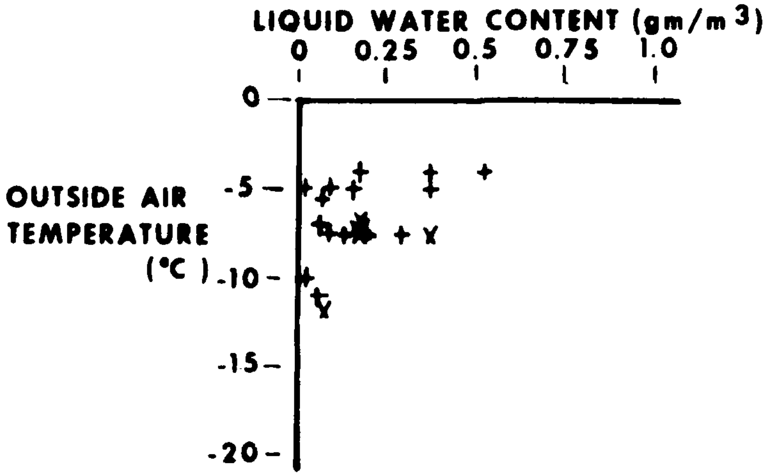
● — 1980 Icing season IR SUPPRESSOR CONFIGURATION ALQ-144COUNTER MEASURES DEVICE, M-130 CHAFF DISPENSER

/ — 15 minute maximum

Note: 90 KTAS, average GW 16,460, 258 RPM rotor speed, 354.5 cg (mid)
All anti-ice and deice systems "ON"

FIGURE 2

NATURAL ICING TEST CONDITIONS



Note

Rotor speed 258 RPM
Average GW 16,260 lbs
Airspeed 93 TO 138 KTAS
Average CG •FS 354.2in.
Each condition at least 15 minutes

X — IR SUPPRESSORS, ALQ-144COUNTERMEASURES DEVICE, M-130 CHAFF DISPENSER

+ — STANDARD TAILPIPE, M-130 CHAFF DISPENSER

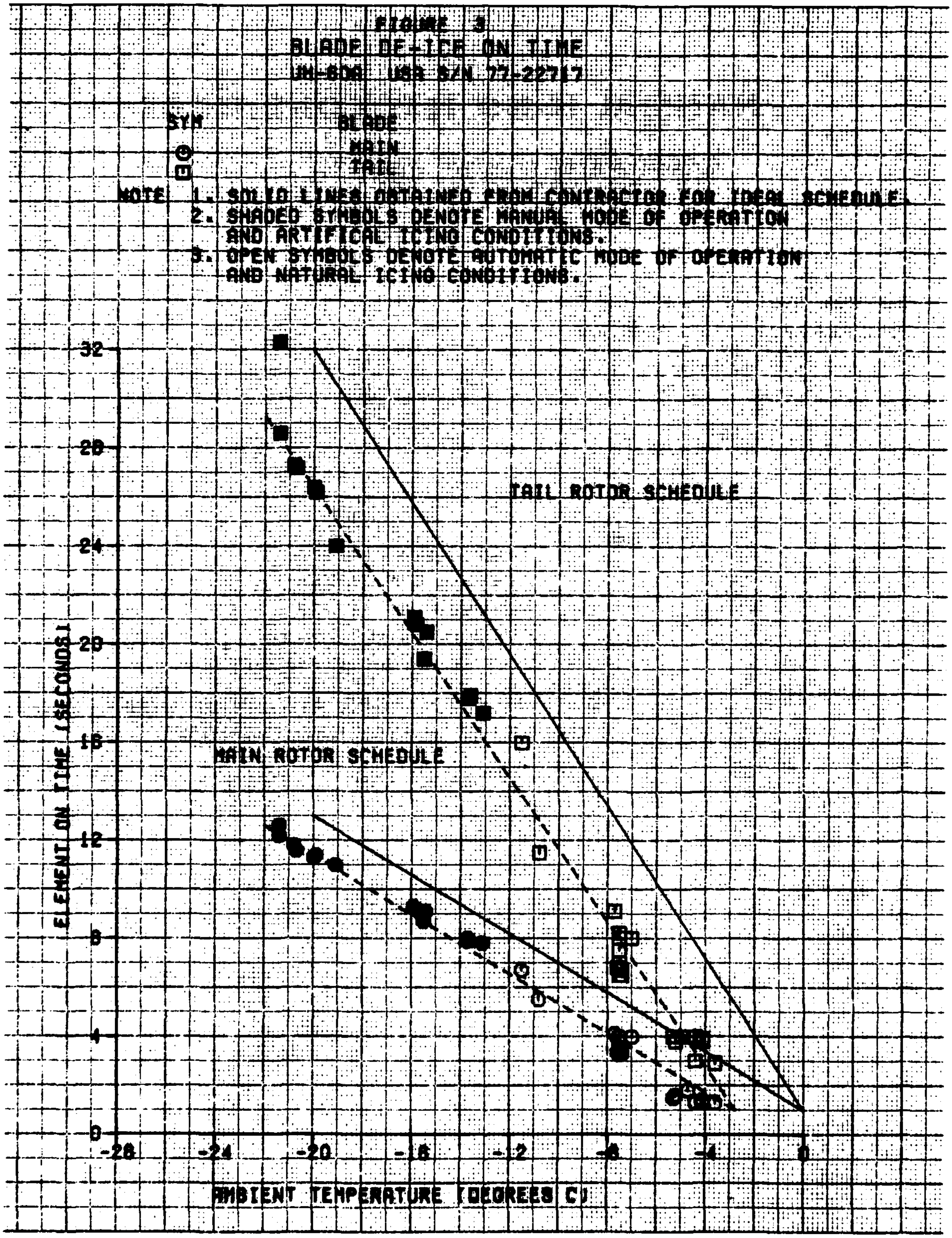


FIGURE 3
BLADE DE-ICE ON TIME
UH-60A USA S/N 77-22717
SYM
BLADE
MAIN
TAIL
NOTE 1. SOLID LINES OBTAINED FROM CONTRACTOR FOR IDEAL SCHEDULE.
2. SHADED SYMBOLS DENOTE MANUAL MODE OF OPERATION AND ARTIFICAL ICING CONDITIONS.
3. OPEN SYMBOLS DENOTE AUTOMATIC MODE OF OPERATION AND NATURAL ICING CONDITIONS.
TAIL ROTOR SCHEDULE
MAIN ROTOR SCHEDULE
ELEMENT ON TIME (SECONDS)
32
28
24
20
16
12
8
4
0
-28
-24
-20
-16
-12
-8
-4
0
AMBIENT TEMPERATURE (DEGREES C)

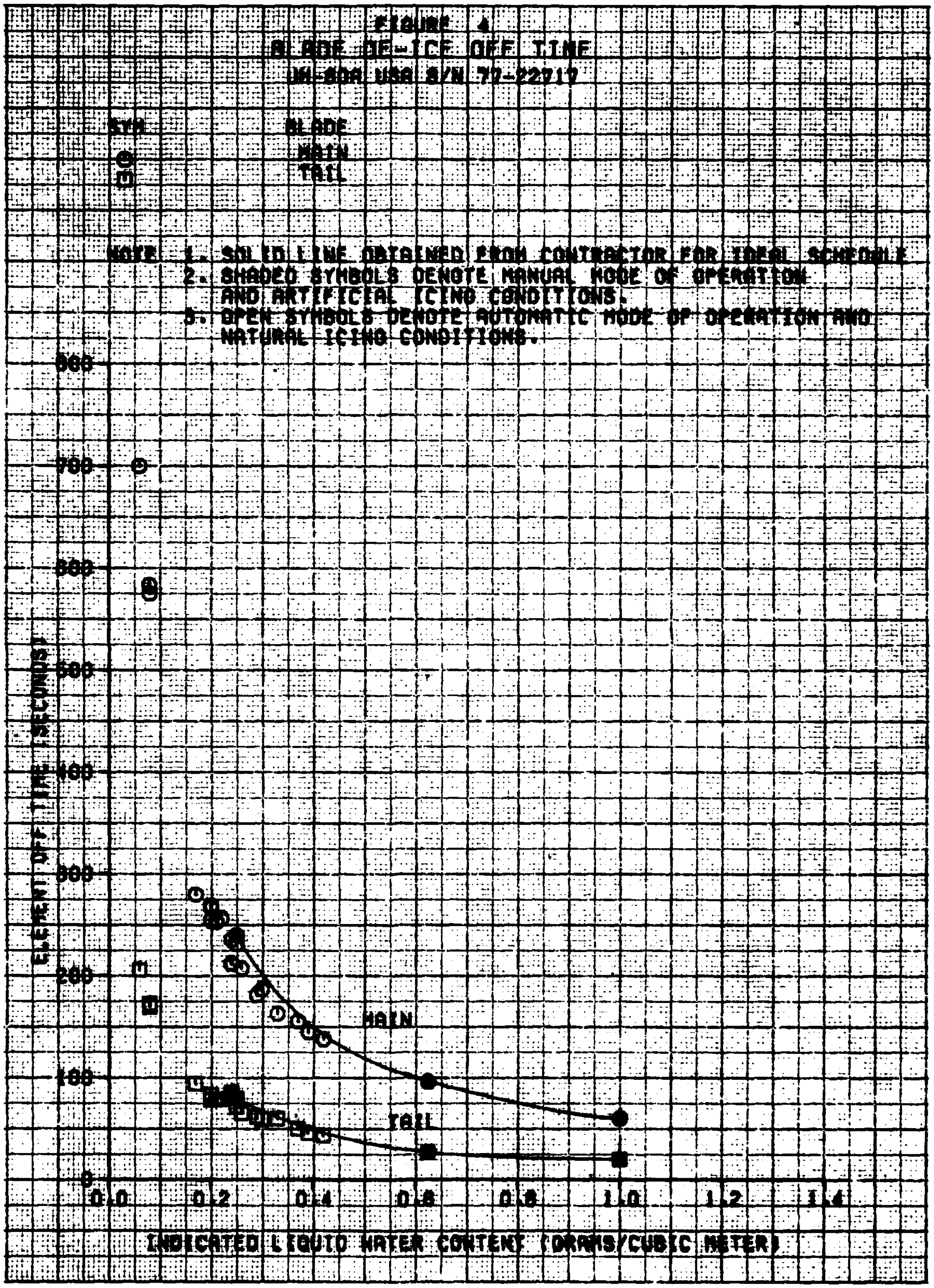


FIGURE 4
BLADE DE-ICE OFF TIME
UH-60A USA S/N 77-22717

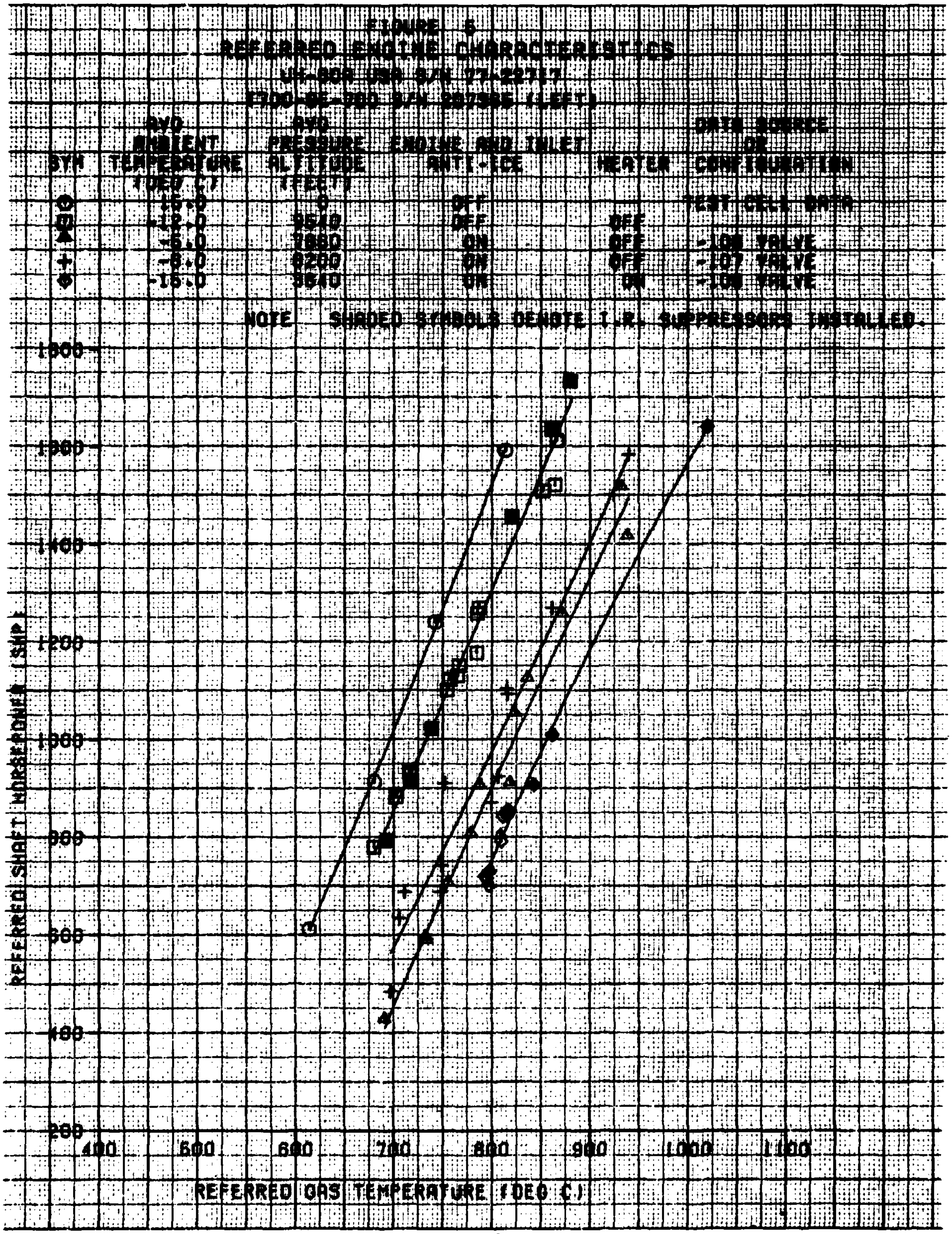


FIGURE 5
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207365 (LEFT)
AVG AMBIENT TEMPERATURE (DEG C)
AVG PRESSURE ALTITUDE (FEET)
ENGINE AND INLET ANTI-ICE
HEATER
DATA SOURCE OR CONFIGURATION
SYM
15.0
0
OFF
TEST CELL DATA
-12.0
9540
OFF
OFF
-6.0
7880
ON
OFF
-106 VALVE
-8.0
8200
ON
OFF
-107 VALVE
-15.0
3640
ON
ON
-106 VALVE
NOTE SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.
REFERRED SHAFT HORSEPOWER (SHP)
1800
1600
1400
1200
1000
800
600
400
200
400
500
600
700
800
900
1000
1100
REFERRED GAS TEMPERATURE (DEG C)

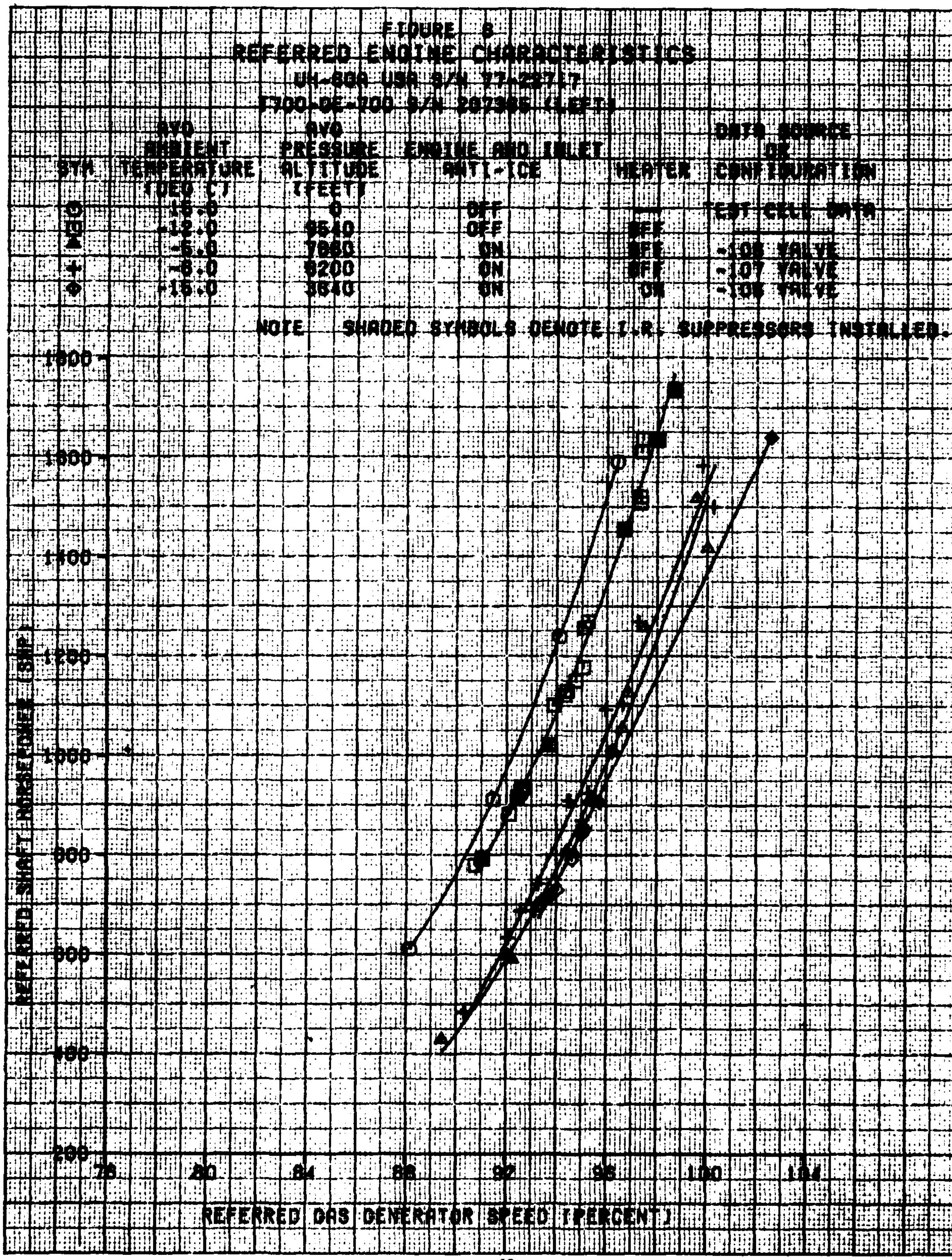


FIGURE 8
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207385 (LEFT)
AVG AMBIENT TEMPERATURE (DEG C)
AVG PRESSURE ALTITUDE (FEET)
ENGINE AND INLET ANTI-ICE
HEATER
DATA SOURCE OR CONFIGURATION
SYM
0
OFF
TEST CELL DATA
-12.0
9540
OFF
OFF
-6.0
7060
ON
OFF
-108 VALVE
-6.0
8200
ON
OFF
-107 VALVE
-15.0
3640
ON
ON
-108 VALVE
NOTE: SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.
1800
1600
1400
1200
1000
800
600
400
200
76
80
84
88
92
96
100
104
REFERRED SHAFT HORSEPOWER (SHP)
REFERRED GAS GENERATOR SPEED (PERCENT)

FIGURE 7
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207366 (LEFT)

SYM	AVG AMBIENT TEMPERATURE (DEG C)	AVG PRESSURE ALTITUDE (FEET)	ENGINE AND INLET ANTI-ICE	HEATER	DATA SOURCE OR CONFIGURATION
○	15.0	0	OFF	---	TEST CELL DATA
□	-12.0	9540	OFF	OFF	———
△	-6.0	7060	ON	OFF	-108 VALVE
+	-6.0	8200	ON	OFF	-107 VALVE
◇	-15.0	3640	ON	ON	-108 VALVE

NOTE SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.

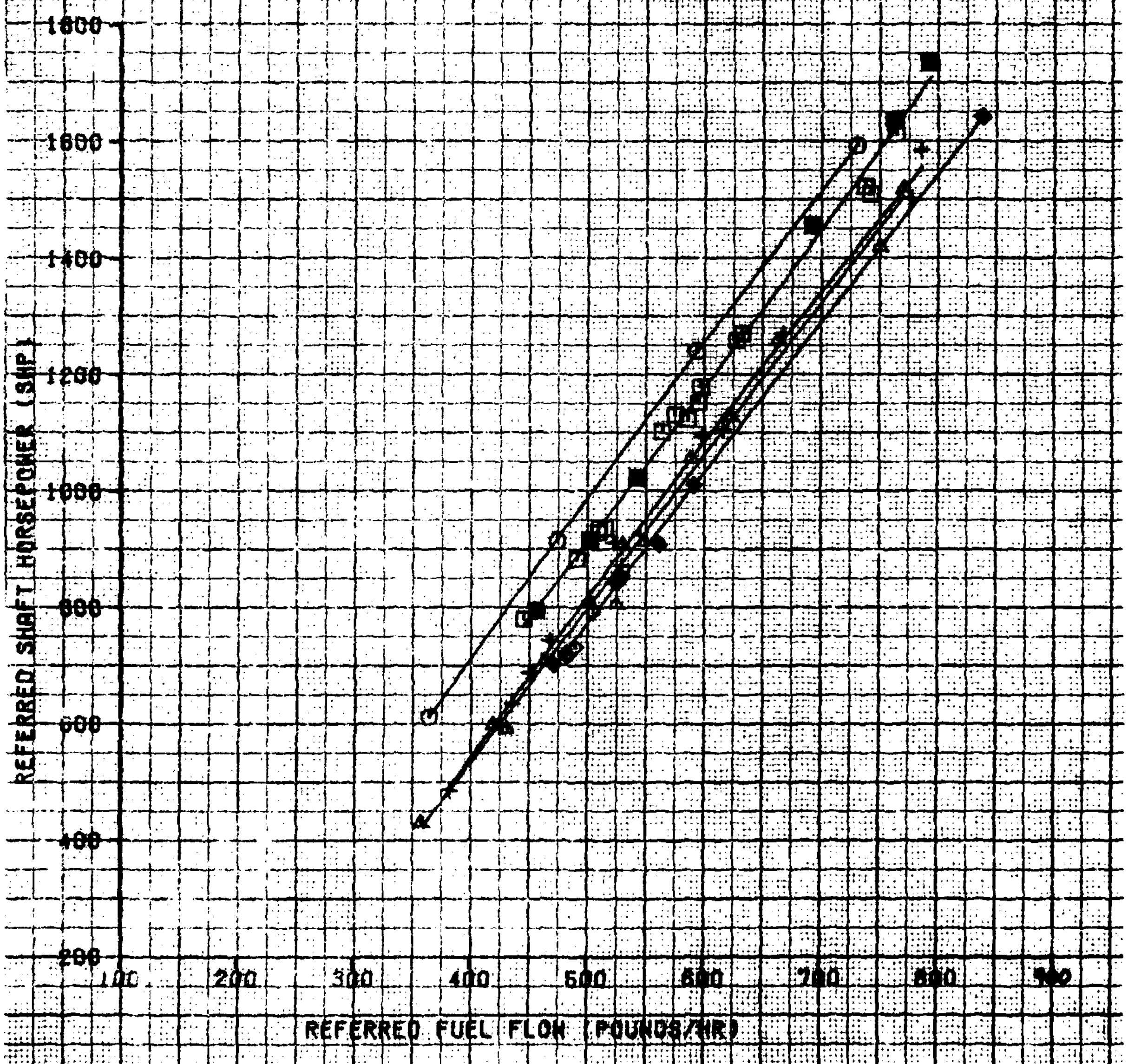
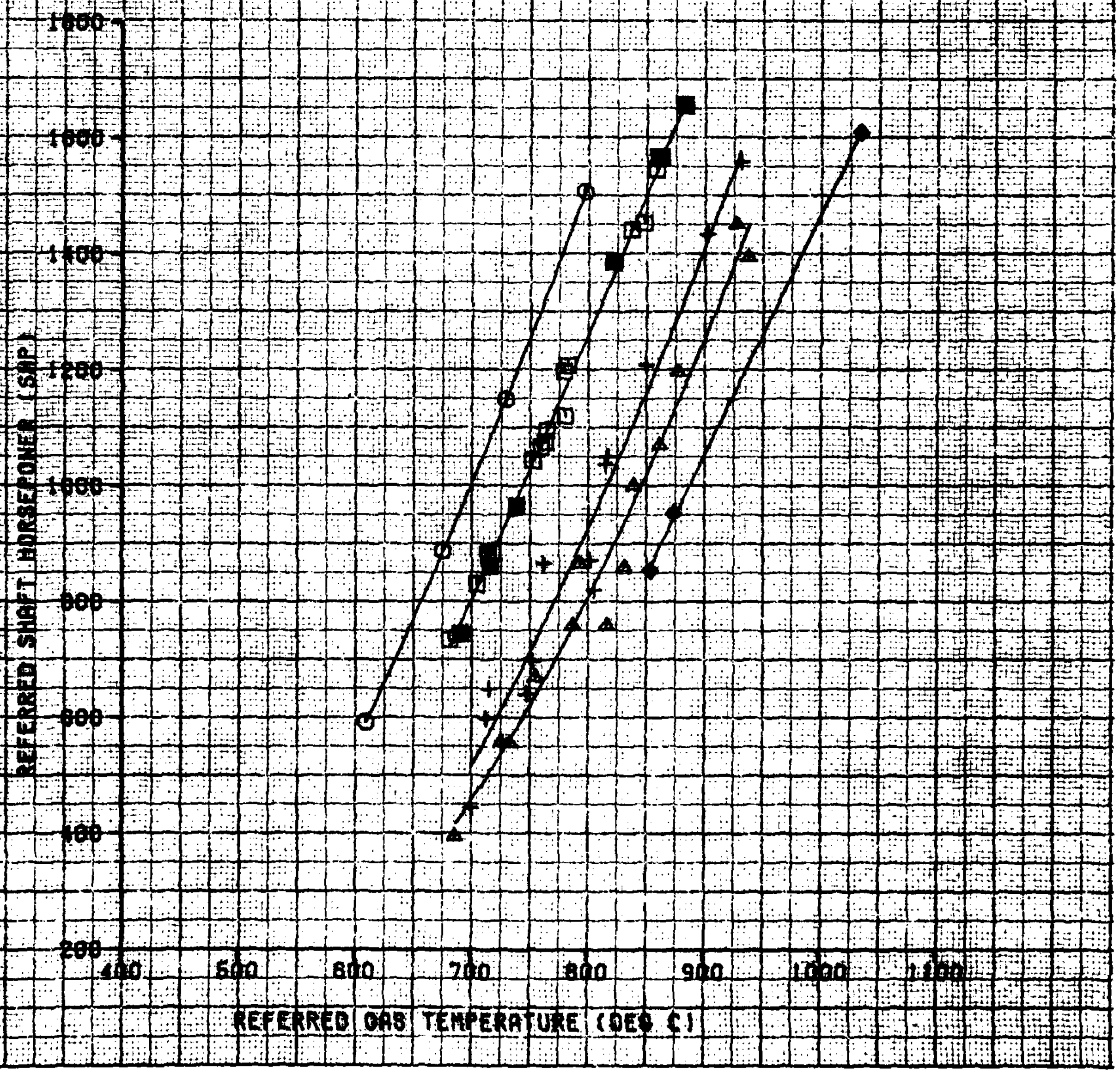


FIGURE 8
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207415 (RIGHT)

SYM	AVG AMBIENT TEMPERATURE (DEG C)	AVG PRESSURE ALTITUDE (FEET)	ENGINE AND INLET ANTI-ICE	HEATER	DATA SOURCE OR CONFIGURATION
○	15.0	0	OFF	—	TEST CELL DATA
□	-12.0	9540	OFF	OFF	
△	-5.0	7860	ON	OFF	-106 VALVE
+	-8.0	8200	ON	OFF	-107 VALVE
◇	-15.0	3640	ON	ON	-106 VALVE

NOTE SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.



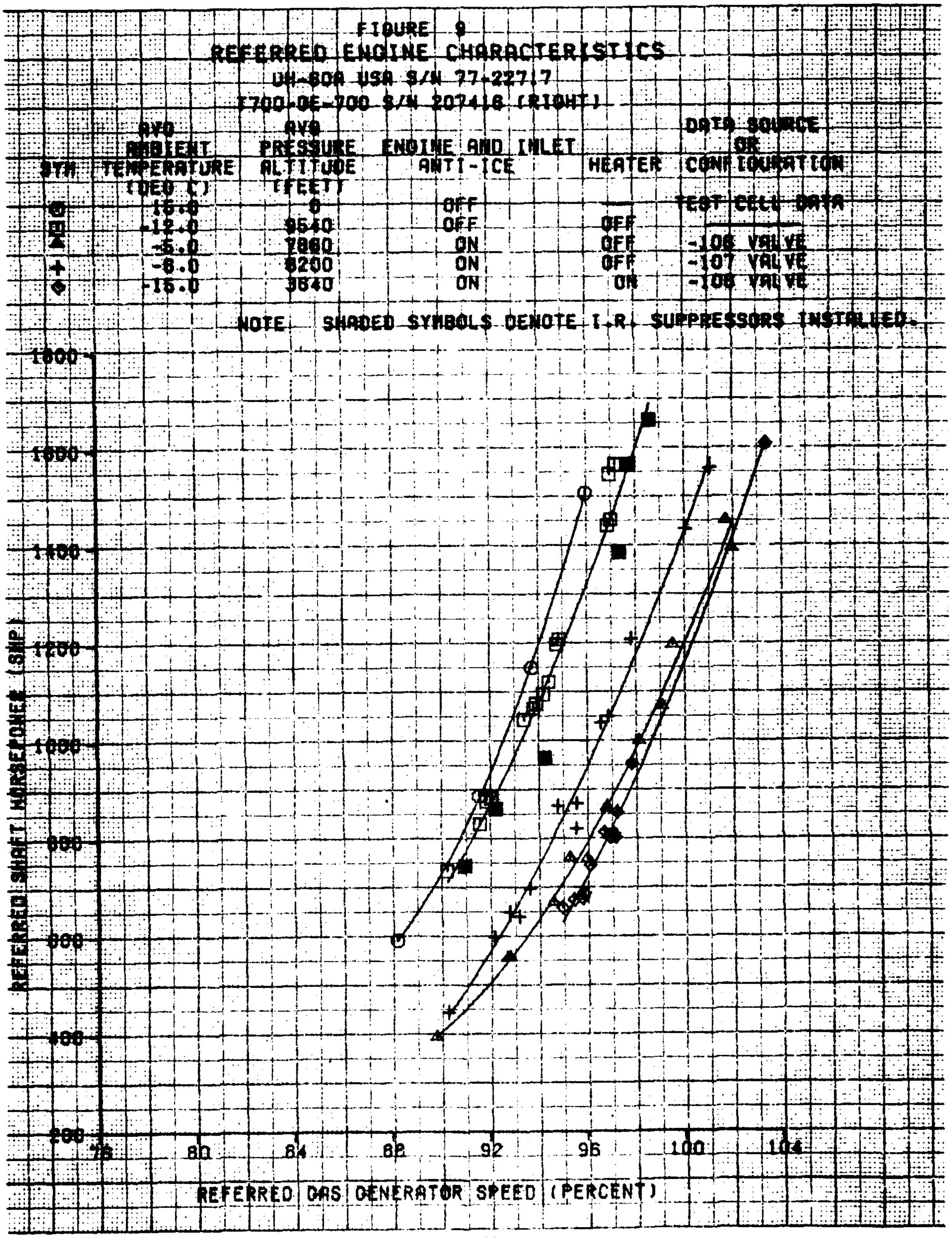


FIGURE 9
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207416 (RIGHT)
SYM | AVG AMBIENT TEMPERATURE (DEG C) | AVG PRESSURE ALTITUDE (FEET) | ENGINE AND INLET ANTI-ICE | HEATER | DATA SOURCE OR CONFIGURATION
15.0 | 0 | OFF | — | TEST CELL DATA
-12.0 | 9540 | OFF | OFF
-5.0 | 7860 | ON | OFF | -106 VALVE
-8.0 | 8200 | ON | OFF | -107 VALVE
-15.0 | 3640 | ON | ON | -108 VALVE
NOTE: SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.
REFERRED SHAFT HORSEPOWER (SHP)
REFERRED GAS GENERATOR SPEED (PERCENT)
1800
1600
1400
1200
1000
800
600
400
200
76
80
84
88
92
96
100
104

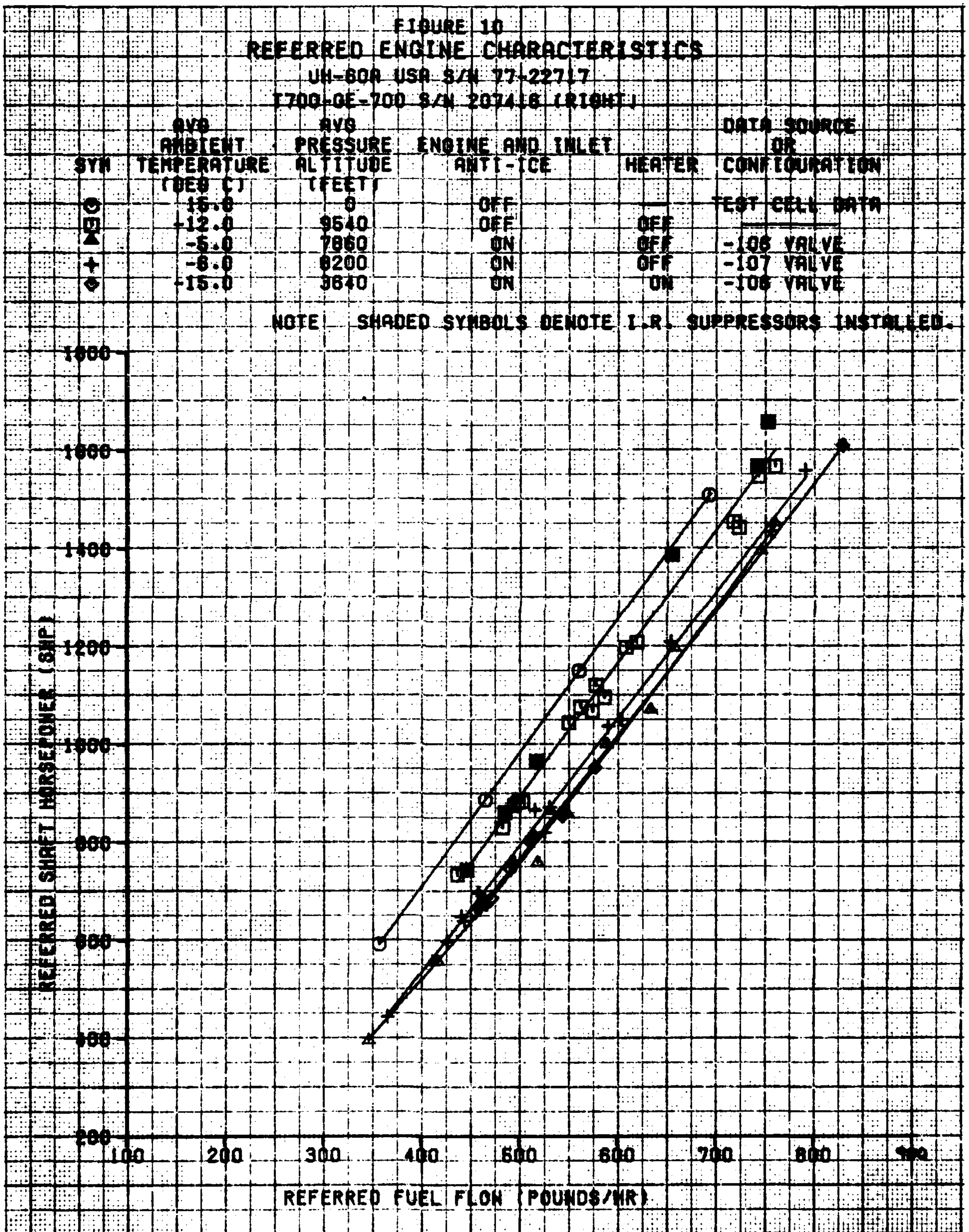


FIGURE 10
REFERRED ENGINE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207416 (RIGHT)
SYM
AVG AMBIENT TEMPERATURE (DEG C)
AVG PRESSURE ALTITUDE (FEET)
ENGINE AND INLET ANTI-ICE
HEATER
DATA SOURCE OR CONFIGURATION
15.0 0 OFF — TEST CELL DATA
-12.0 9540 OFF OFF
-5.0 7860 ON OFF -106 VALVE
-6.0 8200 ON OFF -107 VALVE
-15.0 3640 ON ON -106 VALVE
NOTE: SHADED SYMBOLS DENOTE I.R. SUPPRESSORS INSTALLED.
REFERRED SHAFT HORSEPOWER (SHP)
1800
1600
1400
1200
1000
800
600
400
200
100
200
300
400
500
600
700
800
900
REFERRED FUEL FLOW (POUNDS/HR)

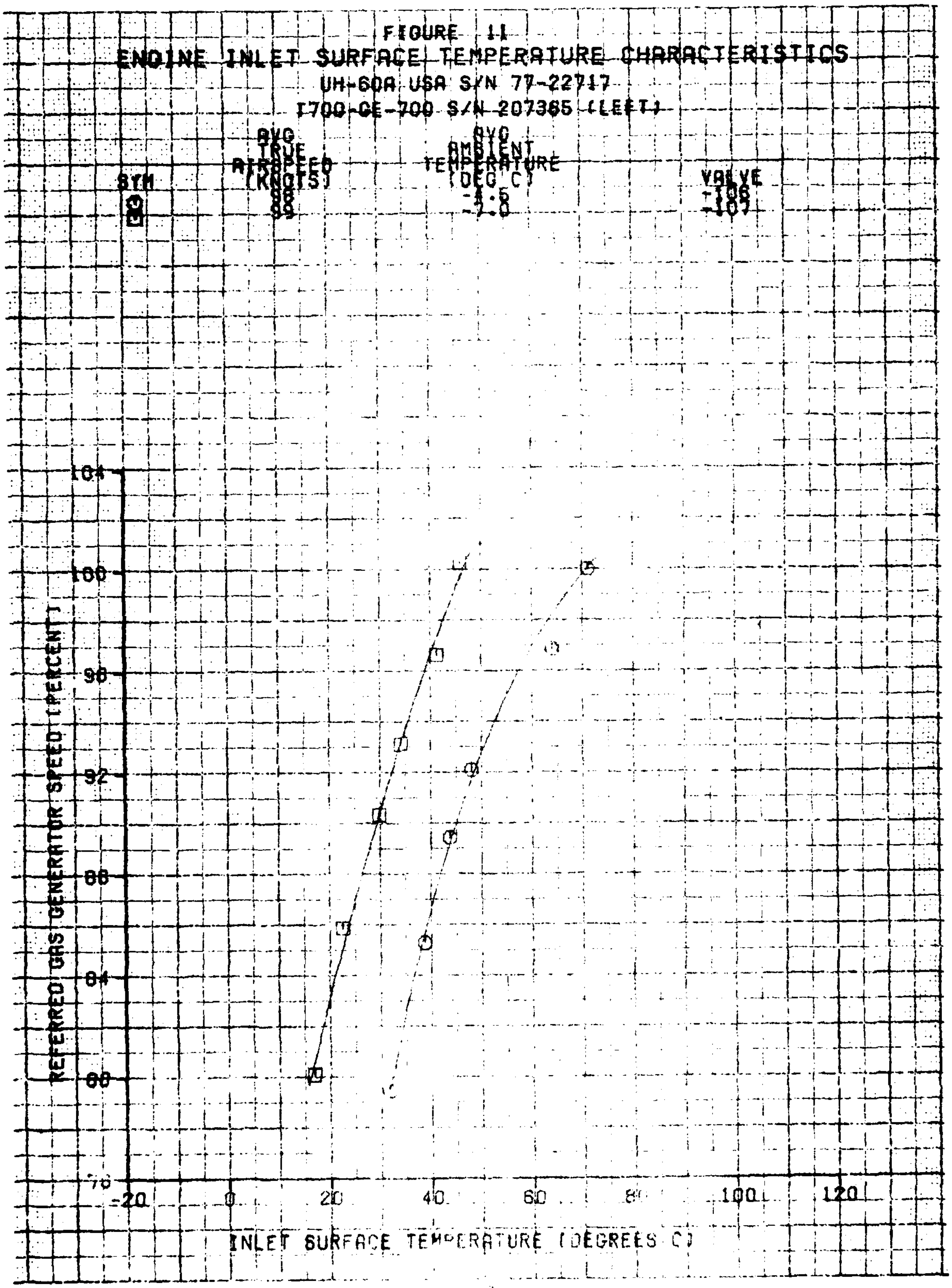


FIGURE 11
ENGINE INLET SURFACE TEMPERATURE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207365 (LEFT)
SYM
AVG TRUE AIRSPEED (KNOTS)
AVG AMBIENT TEMPERATURE (DEG C)
VALVE
88
-4.5
-106
89
-7.0
-107
REFERRED GAS GENERATOR SPEED (PERCENT)
104
100
96
92
88
84
80
76
-20
0
20
40
60
80
100
120
INLET SURFACE TEMPERATURE (DEGREES C)

FIGURE 12
ENGINE INLET SURFACE TEMPERATURE CHARACTERISTICS
UH-60A USA S/N 77-22717
T700-GE-700 S/N 207116 (RIGHT)

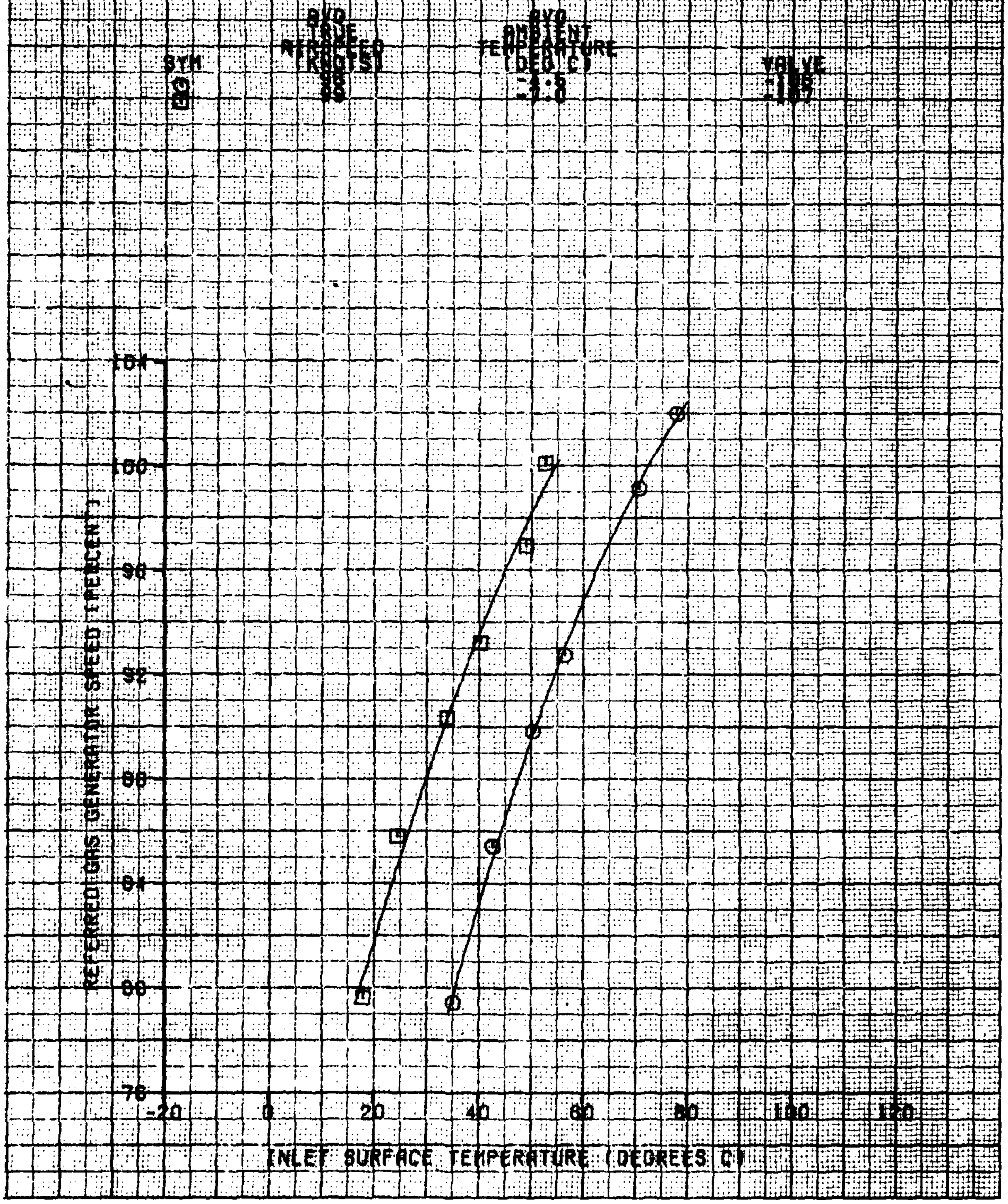


FIGURE 13
BLADE DE-ICE CYCLE
UH-60A USA S/N 77-22717

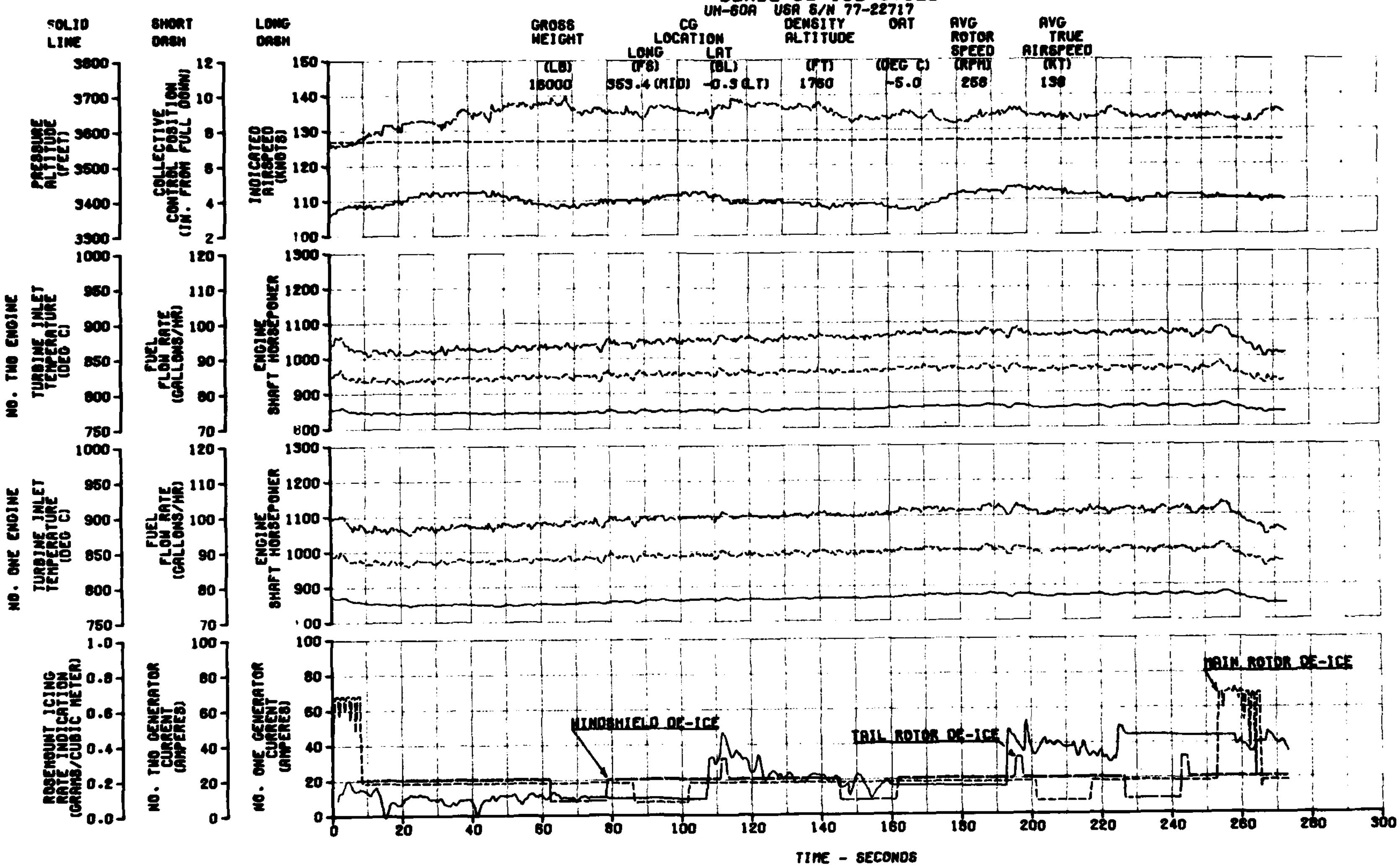


FIGURE 14
BLADE DE-ICE CYCLE
UH-60A USA S/N 77-22717

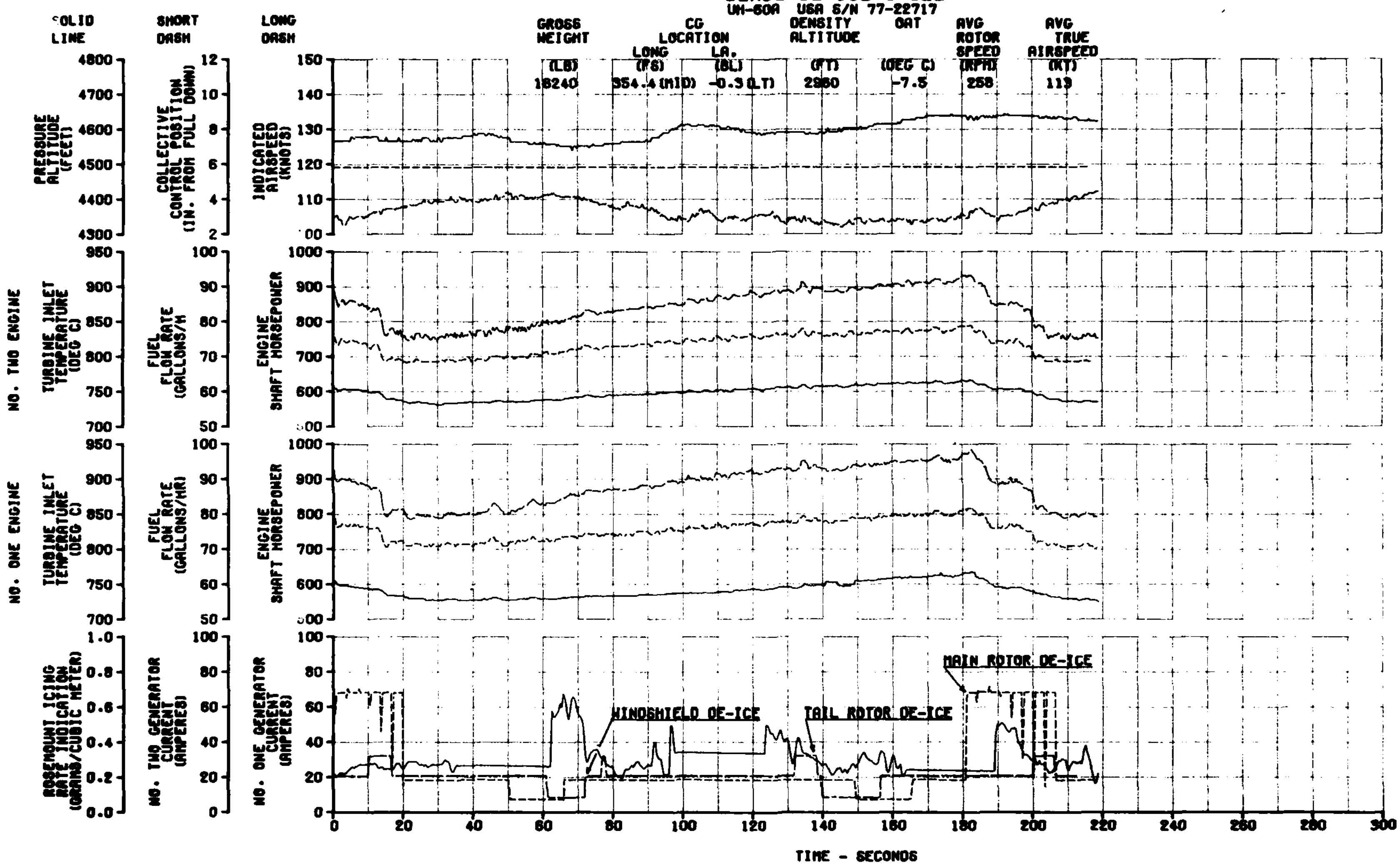
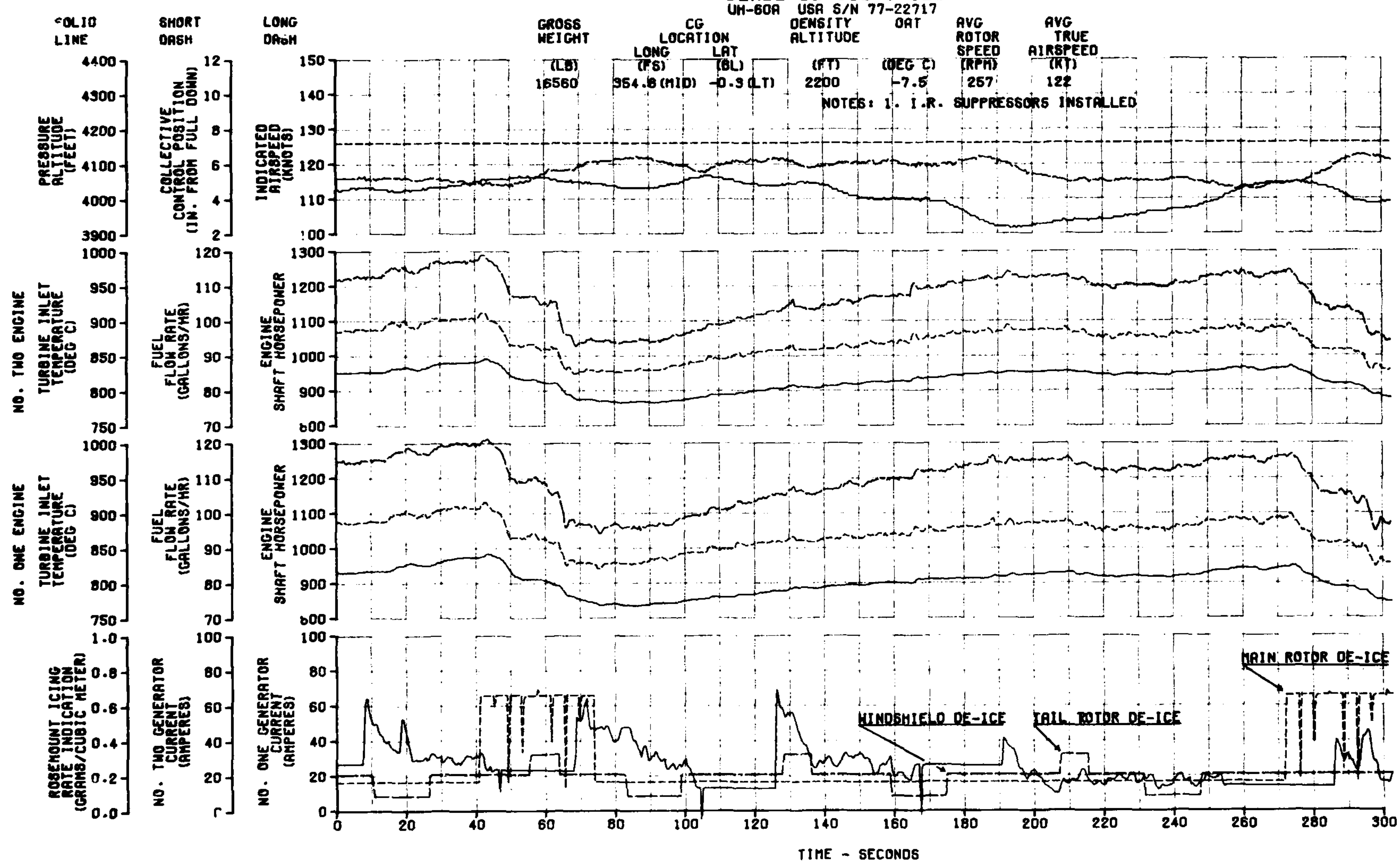


FIGURE 15
BLADE DE-ICE CYCLE
UH-60A USA S/N 77-22717



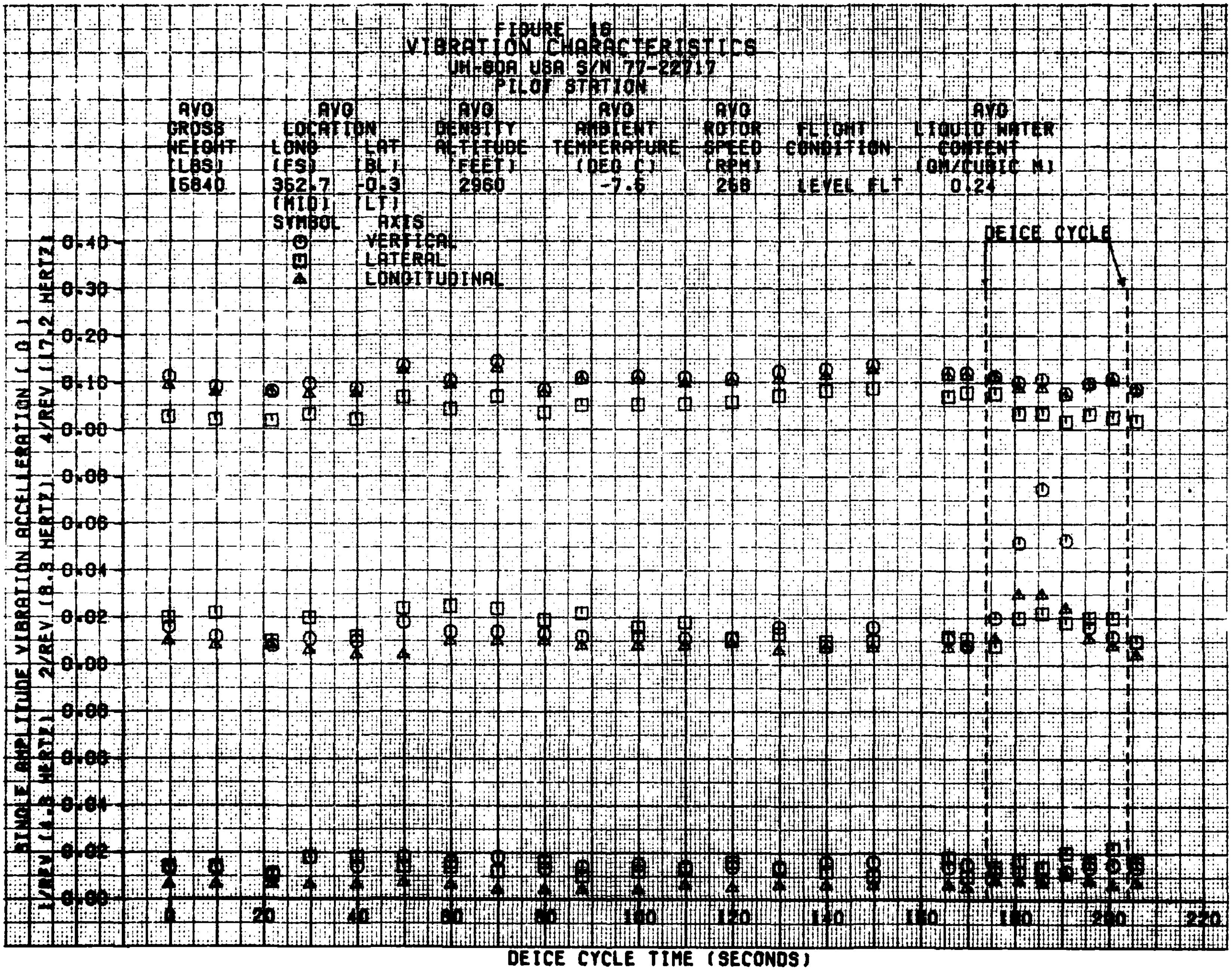


FIGURE 16
VIBRATION CHARACTERISTICS
UH-60A USA S/N 77-22717
PILOT STATION
AVG GROSS WEIGHT (LBS) 15840
AVG LOCATION LONG (FS) 362.7 (MID) LAT (BL) -0.3 (LT)
AVG DENSITY ALTITUDE (FEET) 2960
AVG AMBIENT TEMPERATURE (DEG C) -7.5
AVG ROTOR SPEED (RPM) 258
FLIGHT CONDITION LEVEL FLT
AVG LIQUID WATER CONTENT (GM/CUBIC M) 0.24
SYMBOL AXIS
VERTICAL
LATERAL
LONGITUDINAL
DEICE CYCLE
SINGLE AMPLITUDE VIBRATION ACCELERATION (G)
1/REV (4.3 HERTZ)
2/REV (8.6 HERTZ)
4/REV (17.2 HERTZ)
DEICE CYCLE TIME (SECONDS)

FIGURE 17
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
PILOT SEAT VERTICAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING

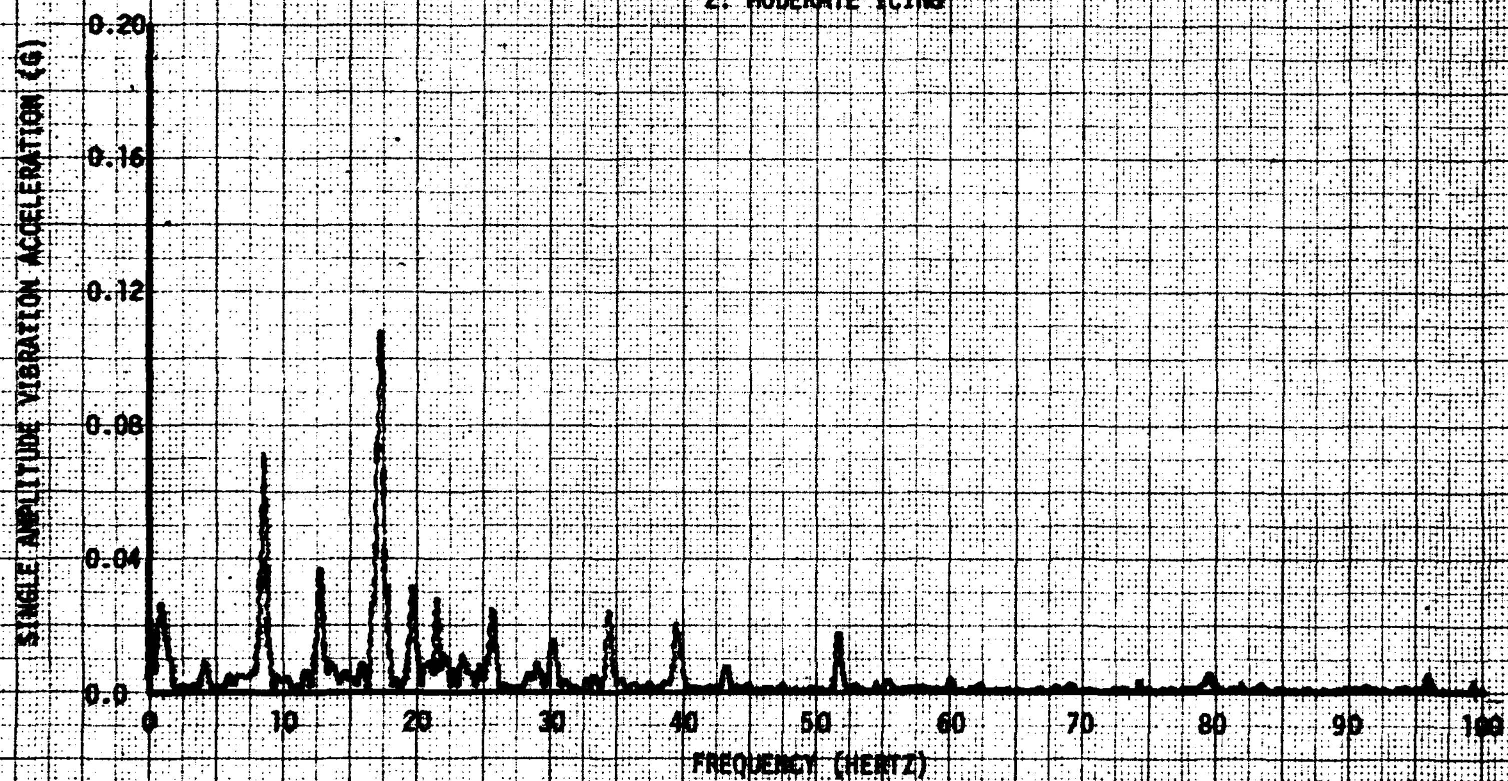


FIGURE 18
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
PILOT SEAT LATERAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE.
2. MODERATE ICING

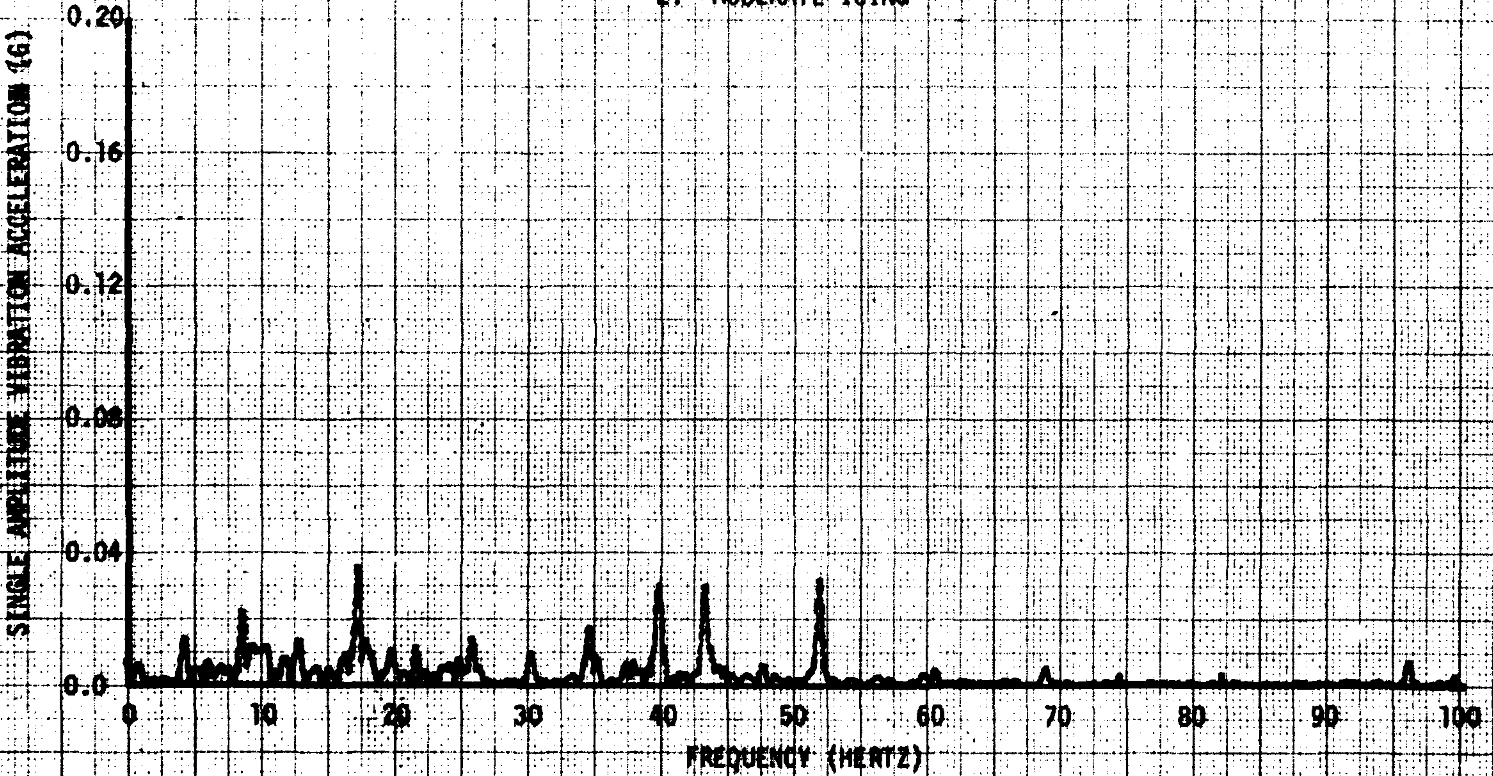


FIGURE 19
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
PILOT SEAT LONGITUDINAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING

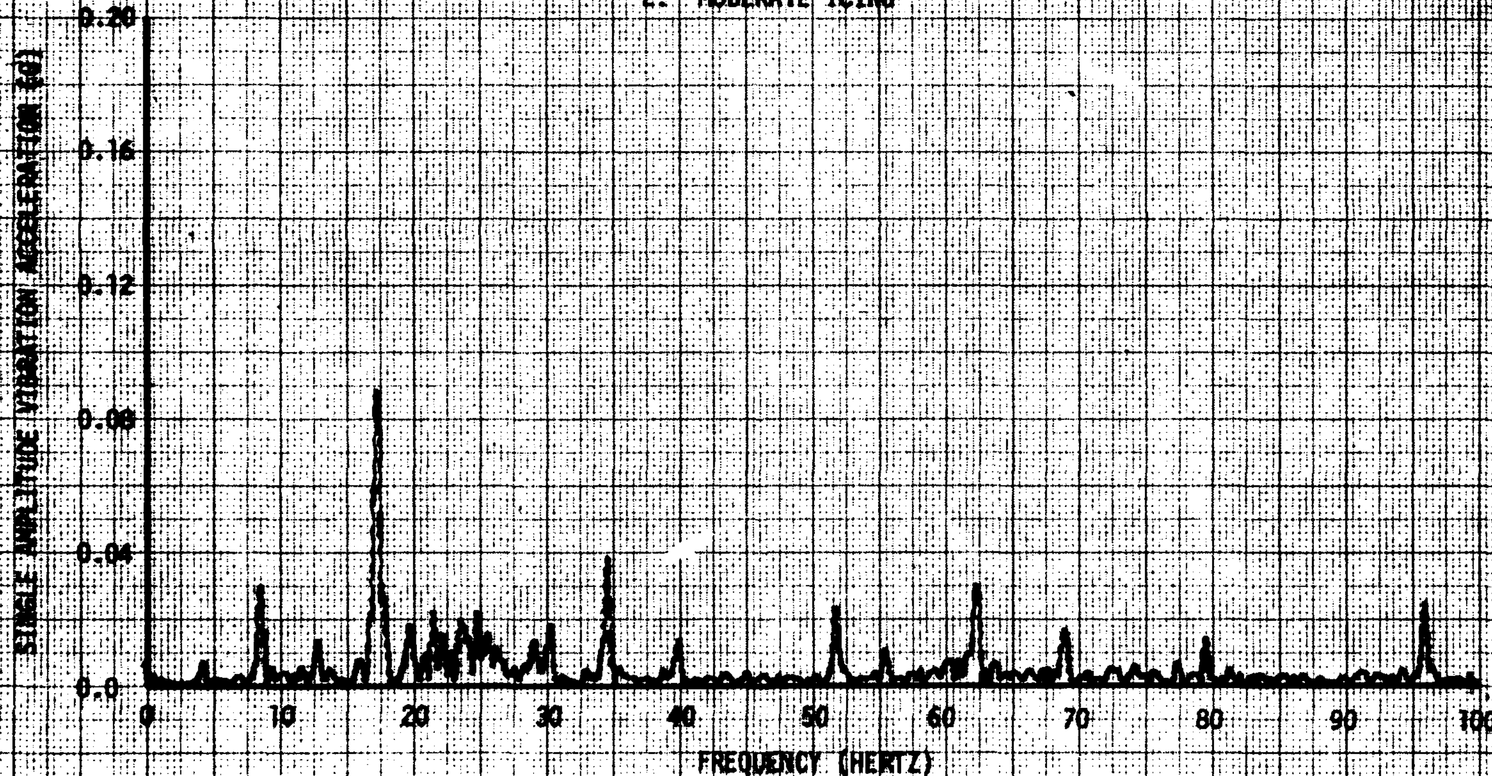


FIGURE 20
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
CENTER OF GRAVITY VERTICAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLIGHT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DE-ICE CYCLE
2. MODERATE ICING

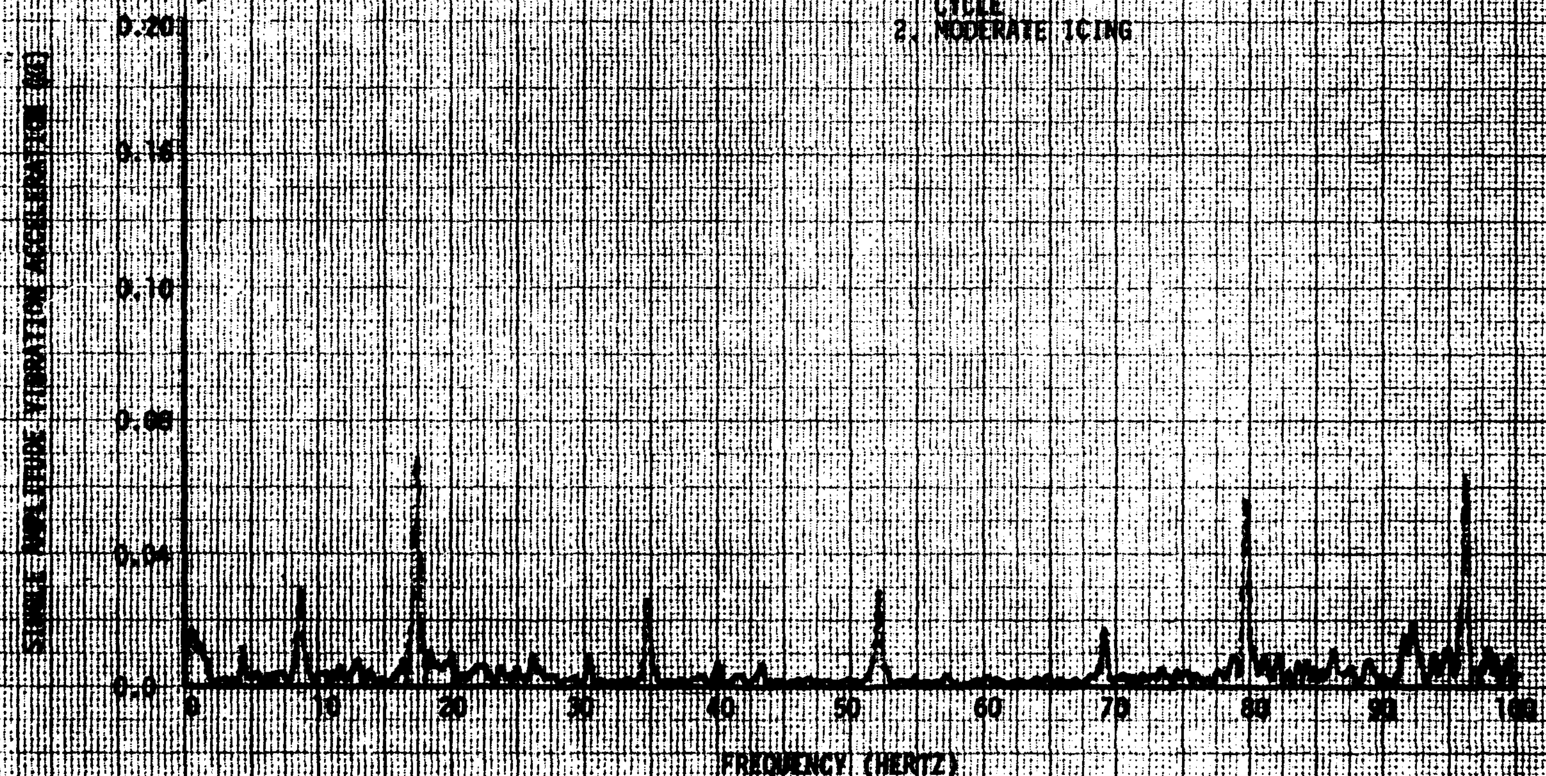
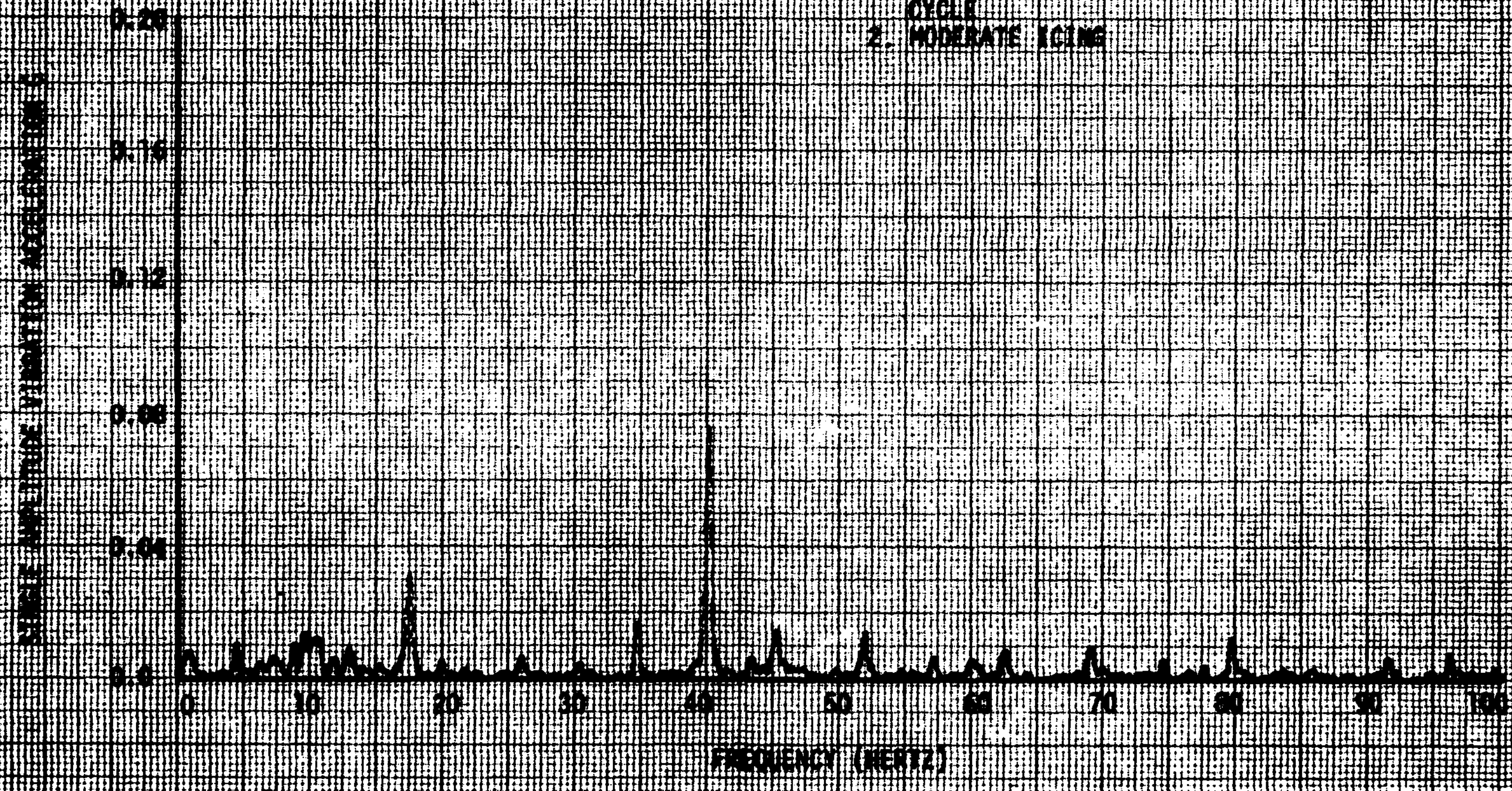


FIGURE 21
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
CENTER OF GRAVITY LATERAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FT)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15800	362.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLIGHT

NOTES: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DE-ICE CYCLE
2. MODERATE ICING



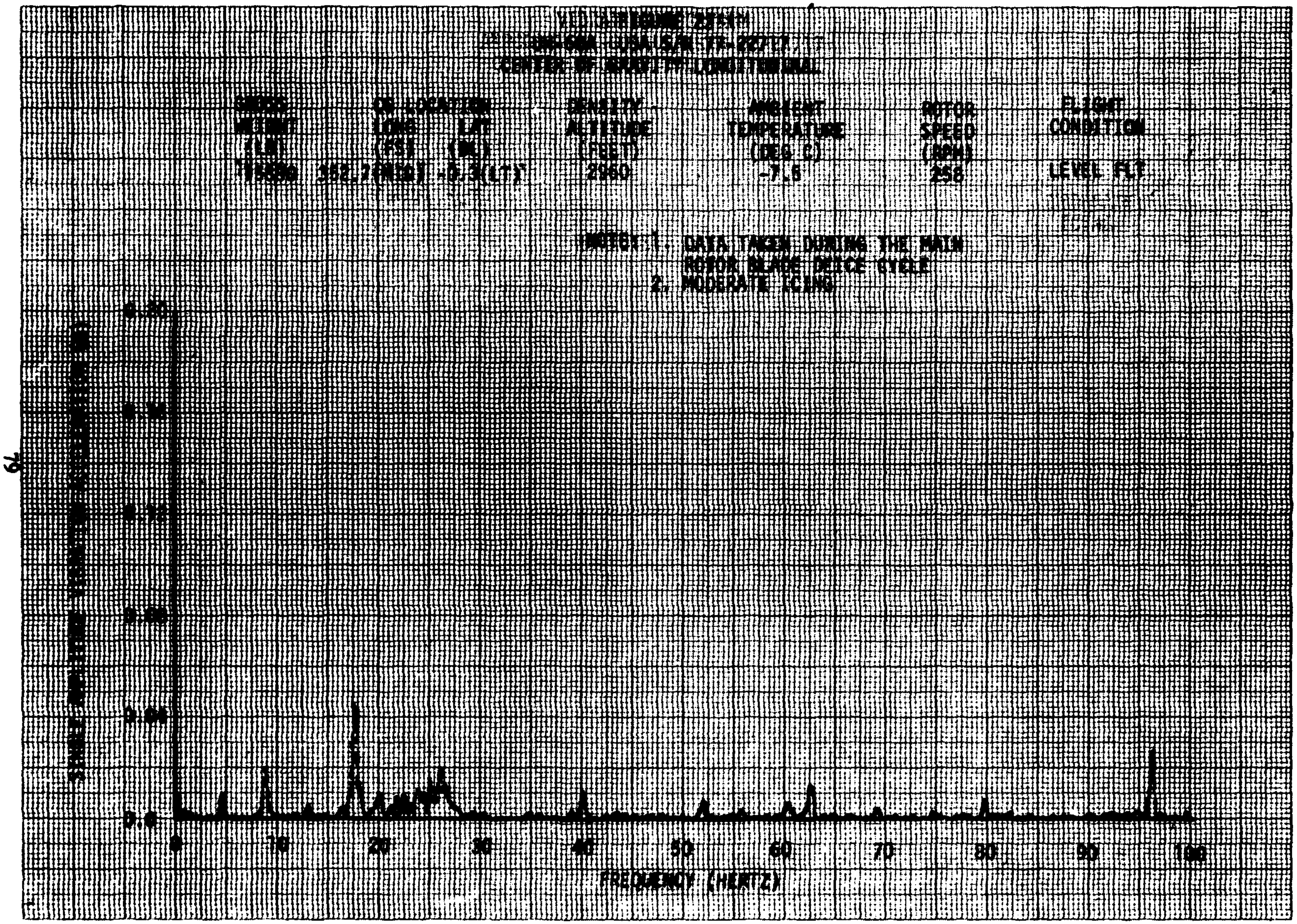

CENTER OF GRAVITY LONGITUDINAL
GROSS WEIGHT (LB)
CG LOCATION LONG (FS) LAT (BL)
DENSITY ALTITUDE (FEET)
AMBIENT TEMPERATURE (DEG C)
ROTOR SPEED (RPM)
FLIGHT CONDITION
352.7(MID) -0.3(LT)
2960
-7.5
258
LEVEL FLT
NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING
0.0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (HERTZ)

FIGURE 23
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
NO. 1 ENGINE EXHAUST FRAME VERTICAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15800	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLIGHT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DE-ICE CYCLE
2. MODERATE ICING

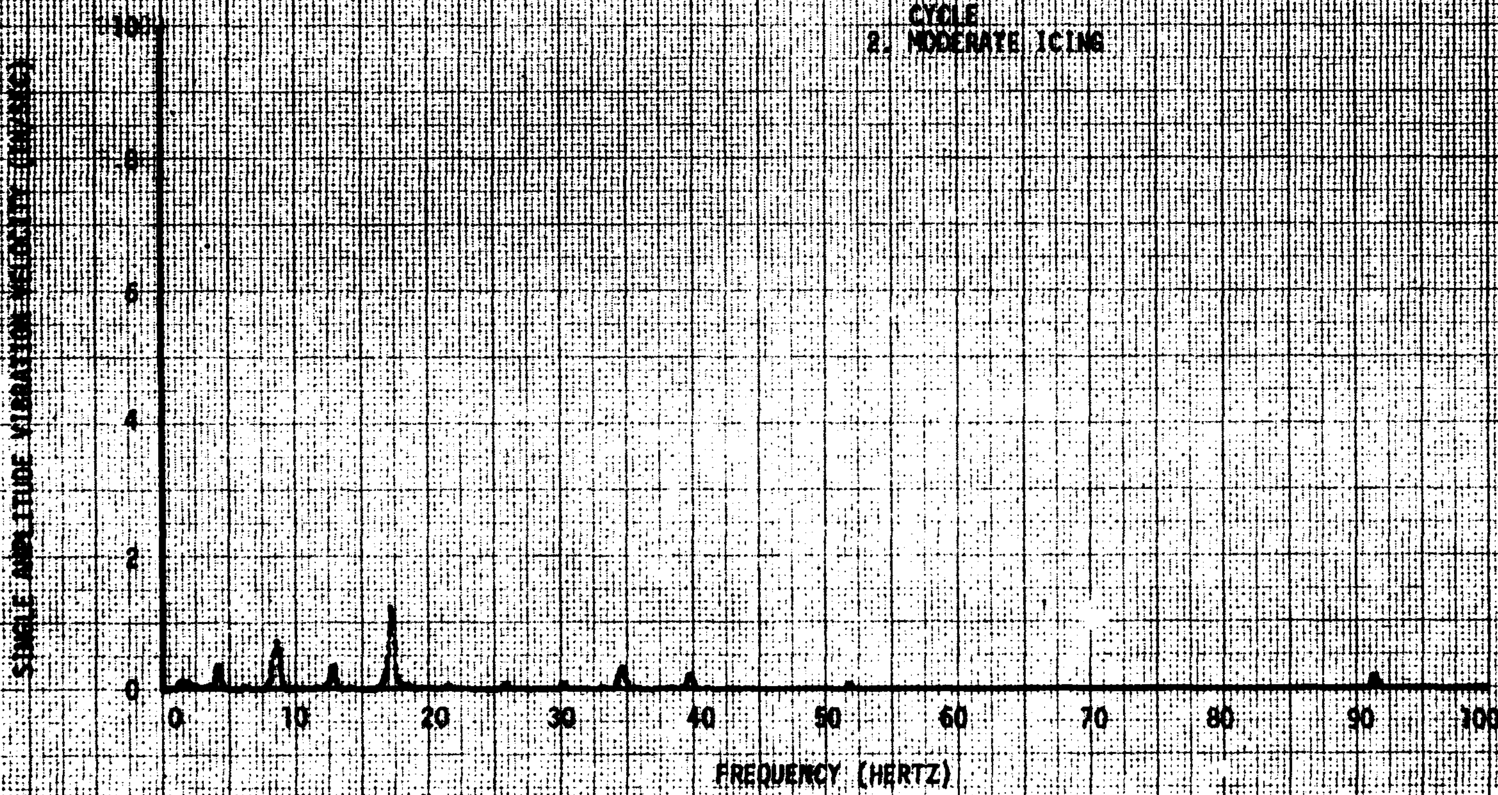


FIGURE 24
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
NO. 1 ENGINE EXHAUST FRAME HORIZONTAL

	GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
●	15800	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING

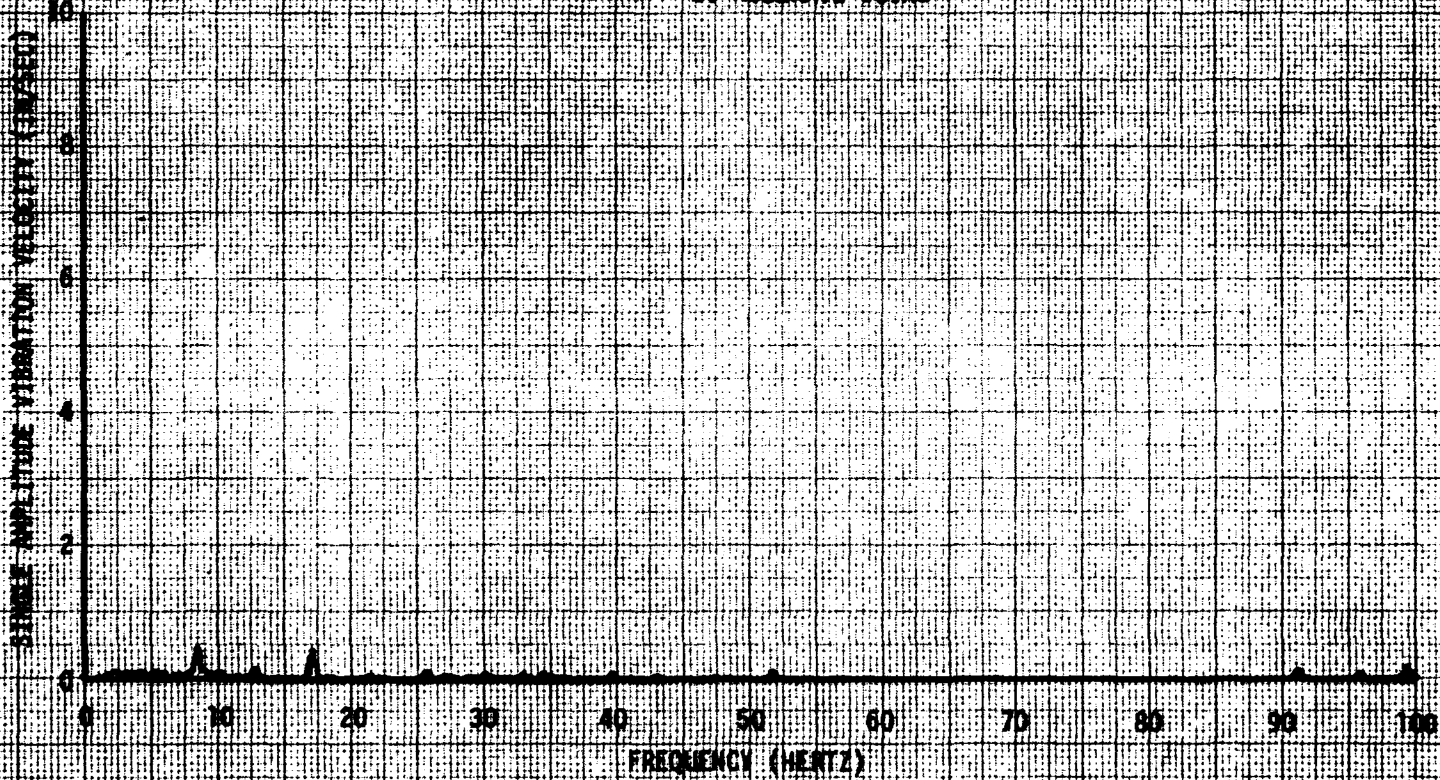


FIGURE 25
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
NO. 2 ENGINE EXHAUST FRAME VERTICAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING

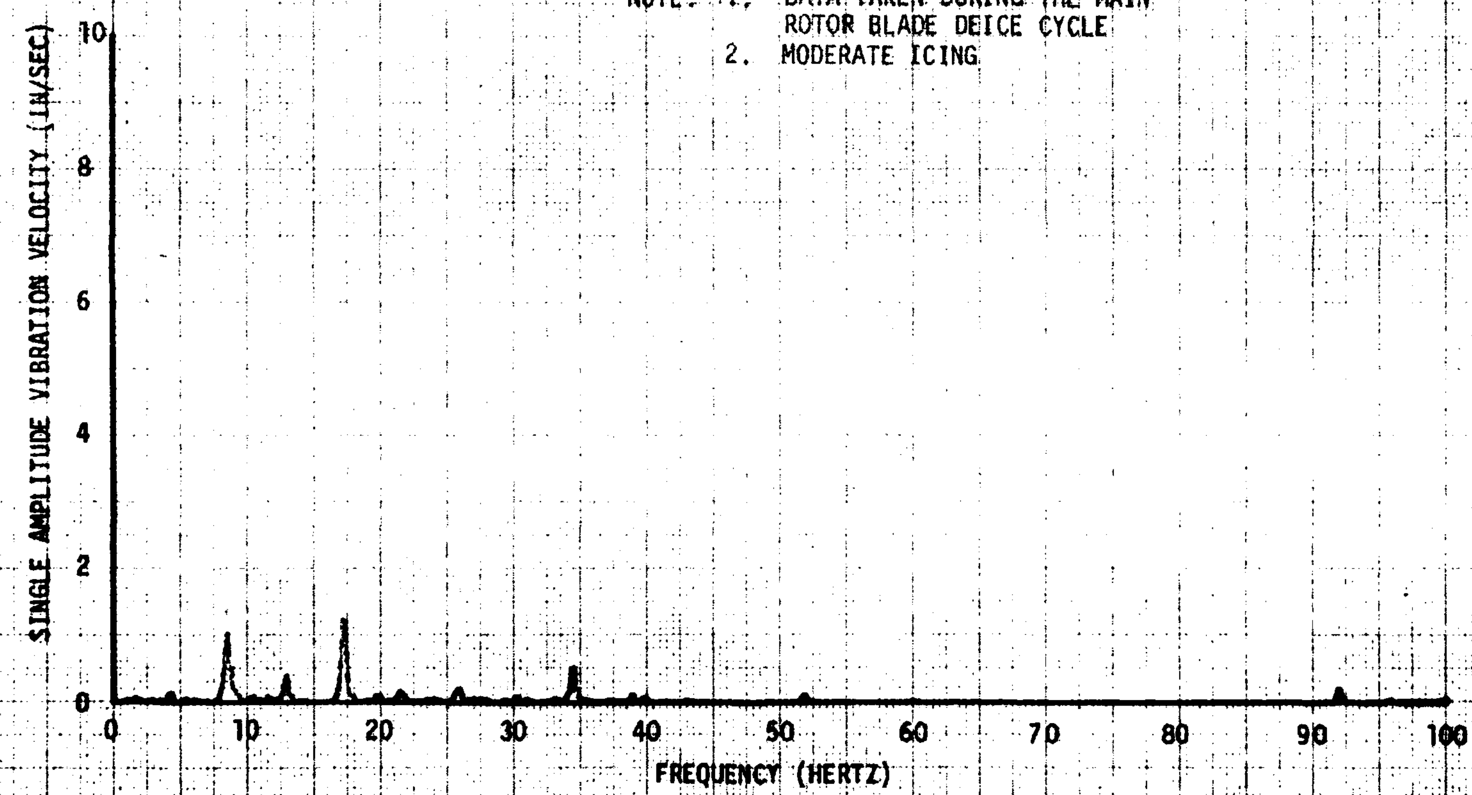


FIGURE 26
VIBRATION SPECTRUM
UH-60A USA S/N 77-22717
NO. 2 ENGINE EXHAUST FRAME HORIZONTAL

GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FEET)	AMBIENT TEMPERATURE (DEG C)	ROTOR SPEED (RPM)	FLIGHT CONDITION
15880	352.7(MID)	-0.3(LT)	2960	-7.5	258	LEVEL FLT

NOTE: 1. DATA TAKEN DURING THE MAIN ROTOR BLADE DEICE CYCLE
2. MODERATE ICING

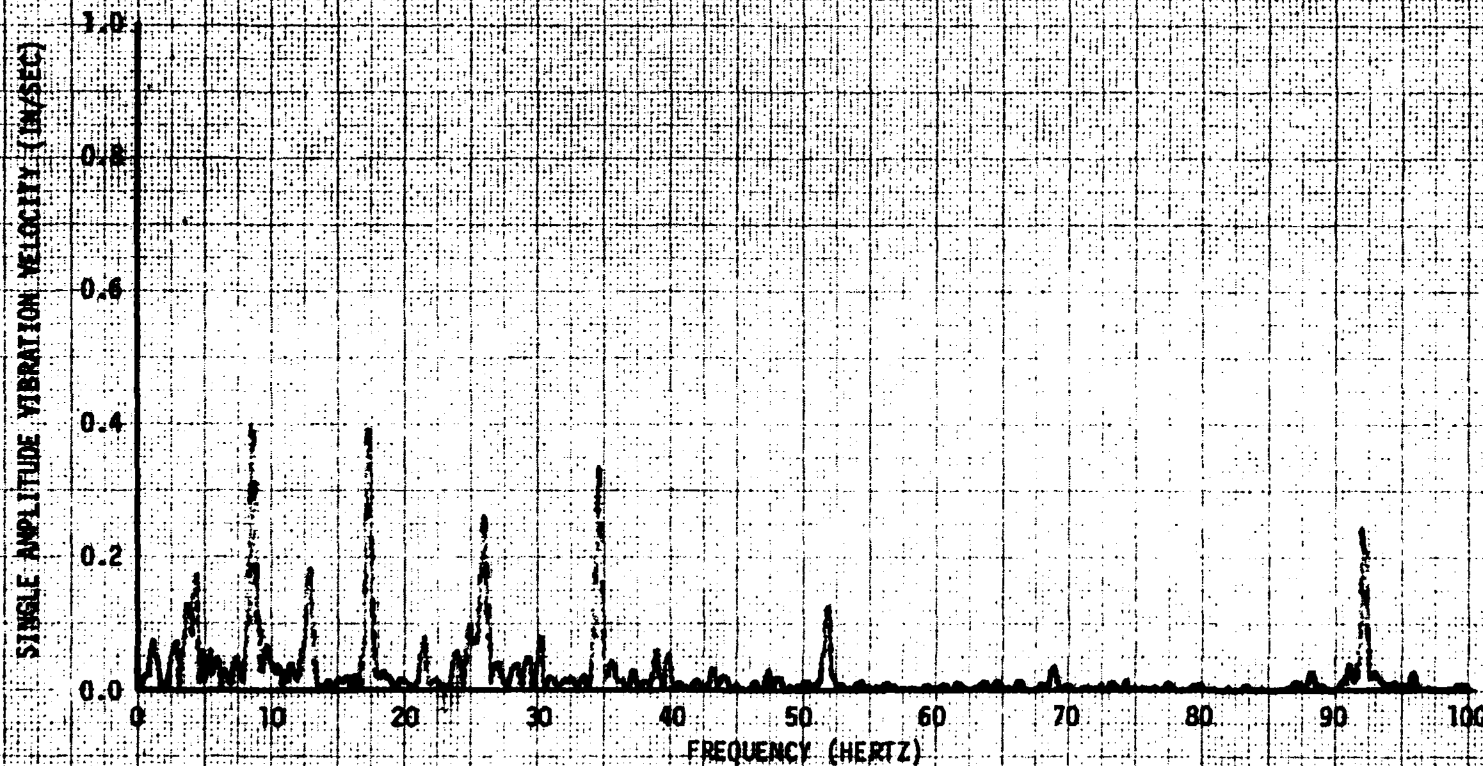
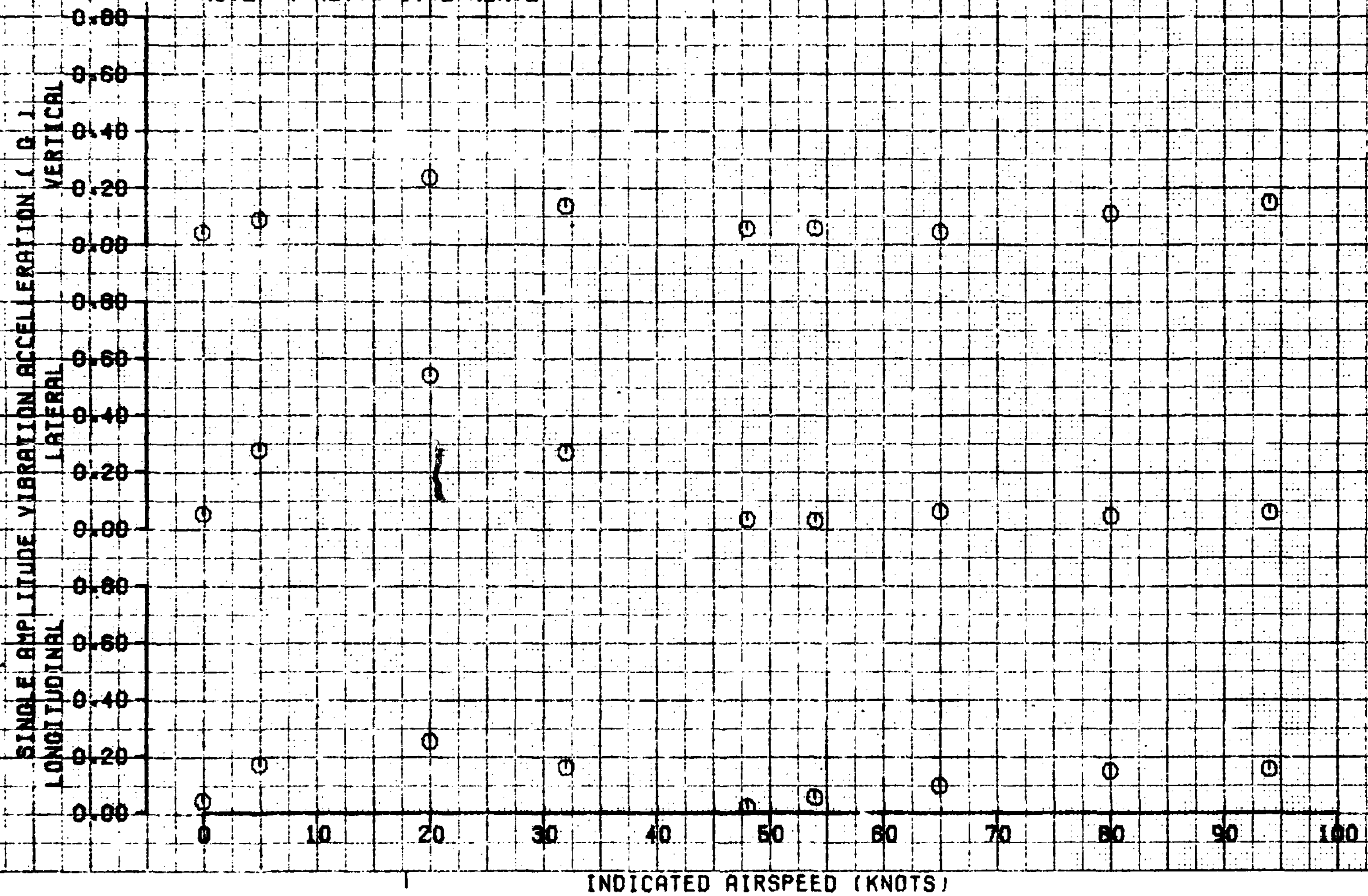


FIGURE 27
VIBRATION CHARACTERISTICS
UH-60A USA S/N 77-22717
PILOT STATION

AVG GROSS WEIGHT (LBS)	AVG LOCATION LONG (FS)	AVG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FEET)	AVG AMBIENT TEMPERATURE (DEG C)	AVG ROTOR SPEED (RPM)	FLIGHT CONDITION
16220	353.6 (MID)	-0.3 (LT)	-780	-3.0	257	DECELERATION TO LANDING

NOTE 4/REV = 17.2 HERTZ



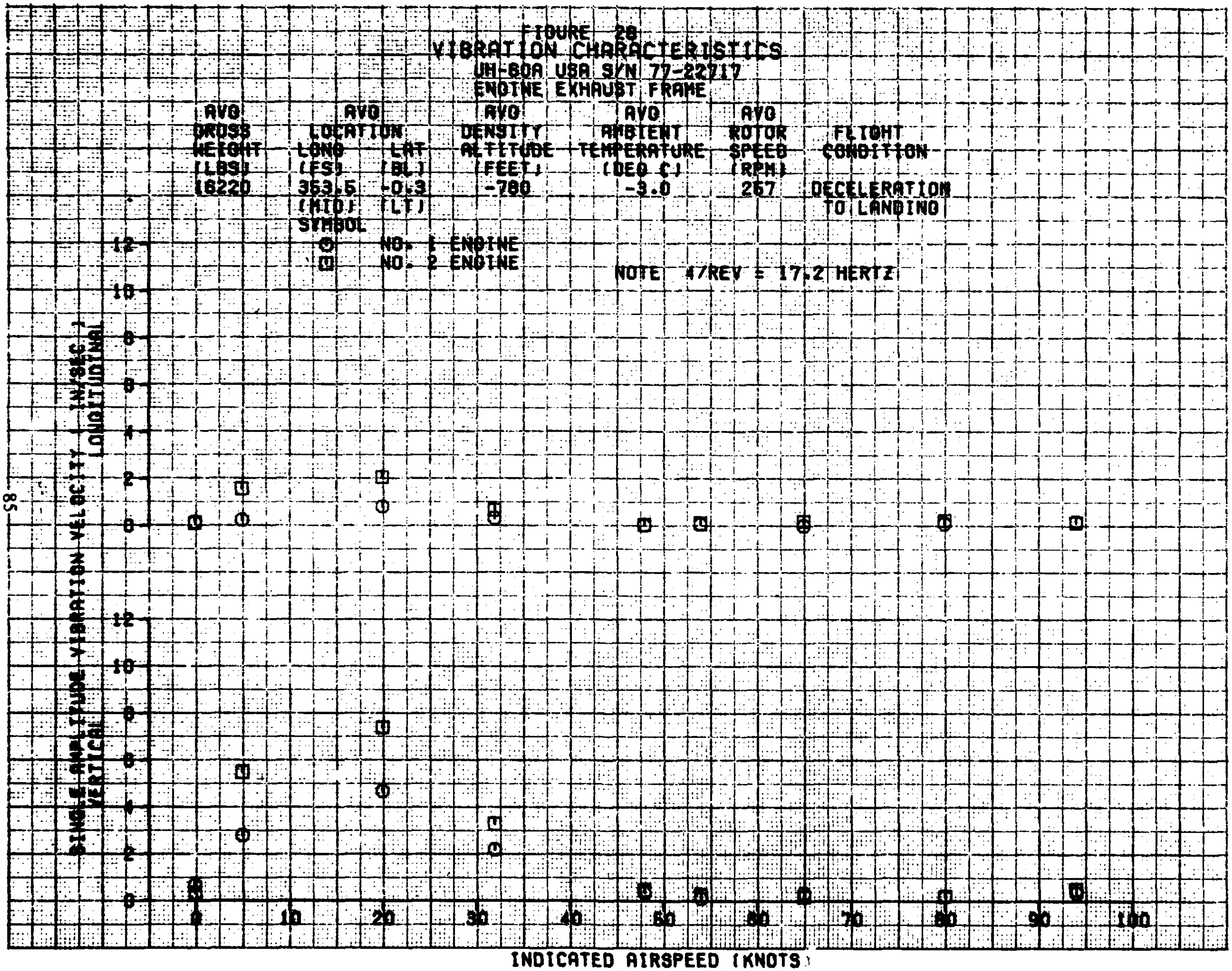


FIGURE 28
VIBRATION CHARACTERISTICS
UH-60A USA S/N 77-22717
ENGINE EXHAUST FRAME
AVG GROSS WEIGHT (LBS) 16220
AVG LOCATION LONG (FS) 353.5 (MID) LAT (BL) -0.3 (LT)
AVG DENSITY ALTITUDE (FEET) -780
AVG AMBIENT TEMPERATURE (DEG C) -3.0
AVG ROTOR SPEED (RPM) 257
FLIGHT CONDITION DECELERATION TO LANDING
SYMBOL
NO. 1 ENGINE
NO. 2 ENGINE
NOTE 4/REV = 17.2 HERTZ
SINGLE AMPLITUDE VIBRATION VELOCITY (IN/SEC)
LONGITUDINAL
VERTICAL
INDICATED AIRSPEED (KNOTS)
0
2
4
6
8
10
12
20
30
40
50
60
70
80
90
100

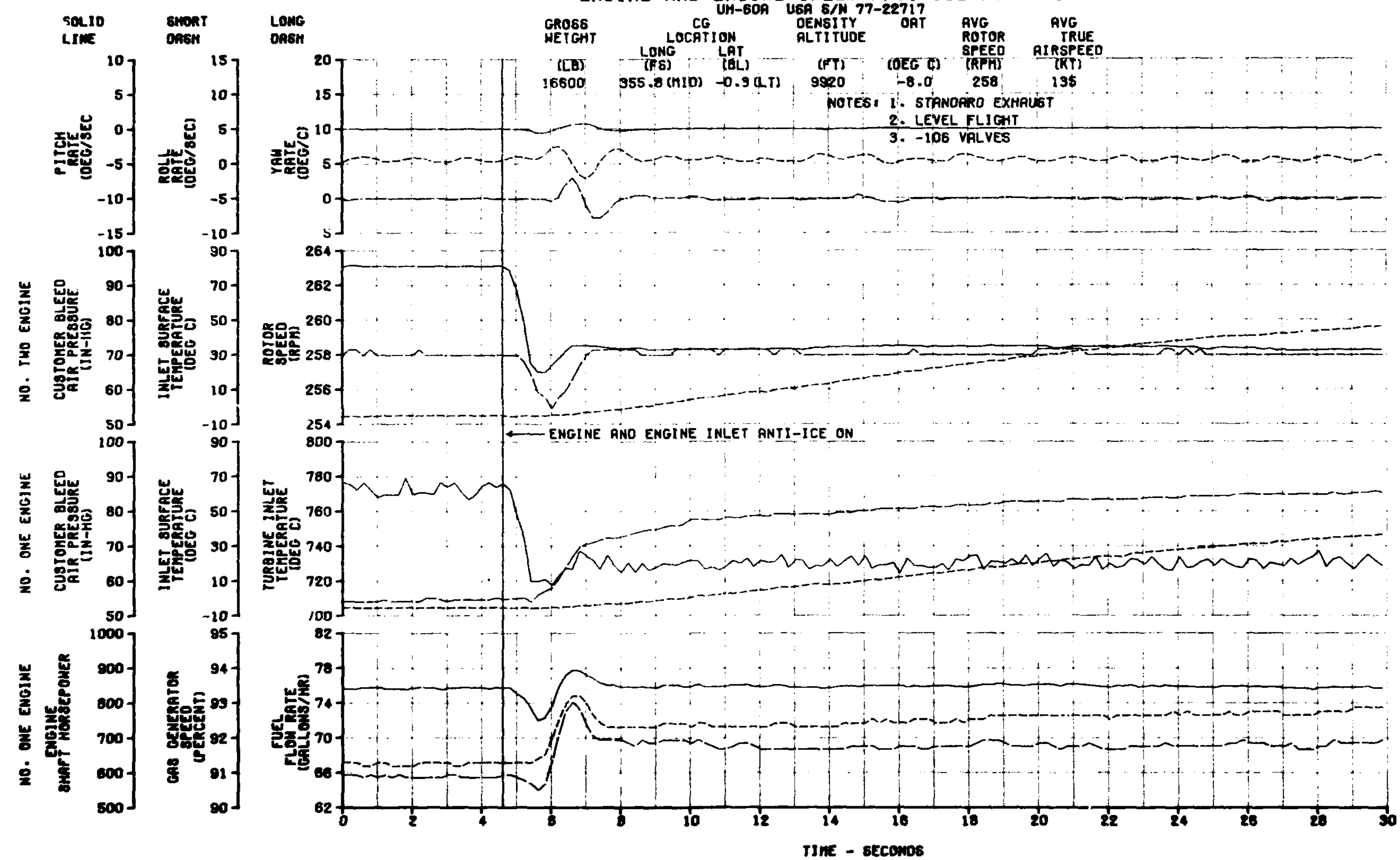
FIGURE 29

ENGINE AND ENGINE INLET ANTI-ICE ACTUATION

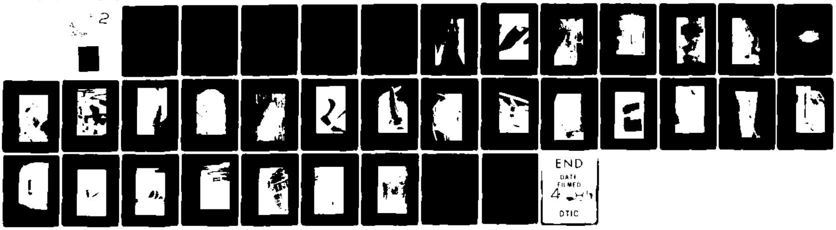
UH-60A USA S/N 77-22717

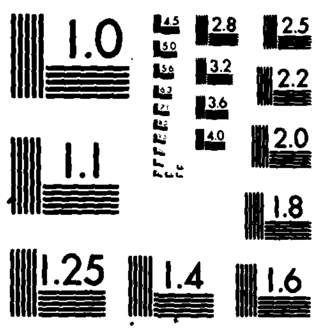
GROSS WEIGHT (LB)	CG LOCATION LONG (FS)	CG LOCATION LAT (BL)	DENSITY ALTITUDE (FT)	OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KT)
16600	355.8 (MID)	-0.3 (LT)	9920	-8.0	258	135

NOTES: 1. STANDARD EXHAUST
2. LEVEL FLIGHT
3. -106 VALVES



AD-A096 239 ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB CA F/G 1/3
ARTIFICIAL AND NATURAL ICING TESTS PRODUCTION UH-60A HELICOPTER--ETC(U)
JUN 80 M L HANKS, L B HIGGINS, V L DIEKMANN
UNCLASSIFIED USAAEFA-79-19 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FIGURE 30

ENGINE AND ENGINE INLET ANTI-ICE ACTUATION

UH-60A USA S/N 77-22717

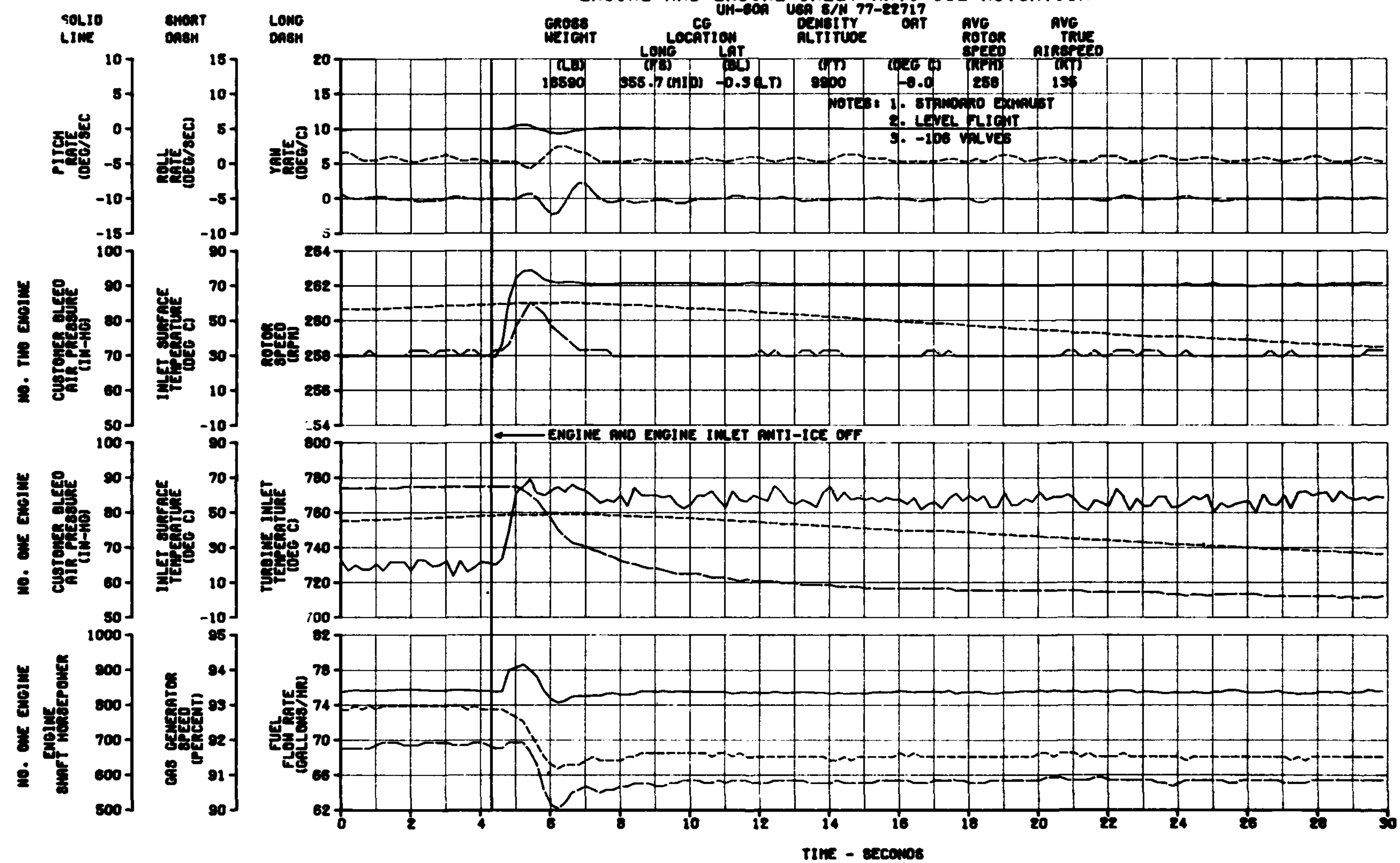


FIGURE 31
ENGINE AND ENGINE INLET ANTI-ICE ACTUATION

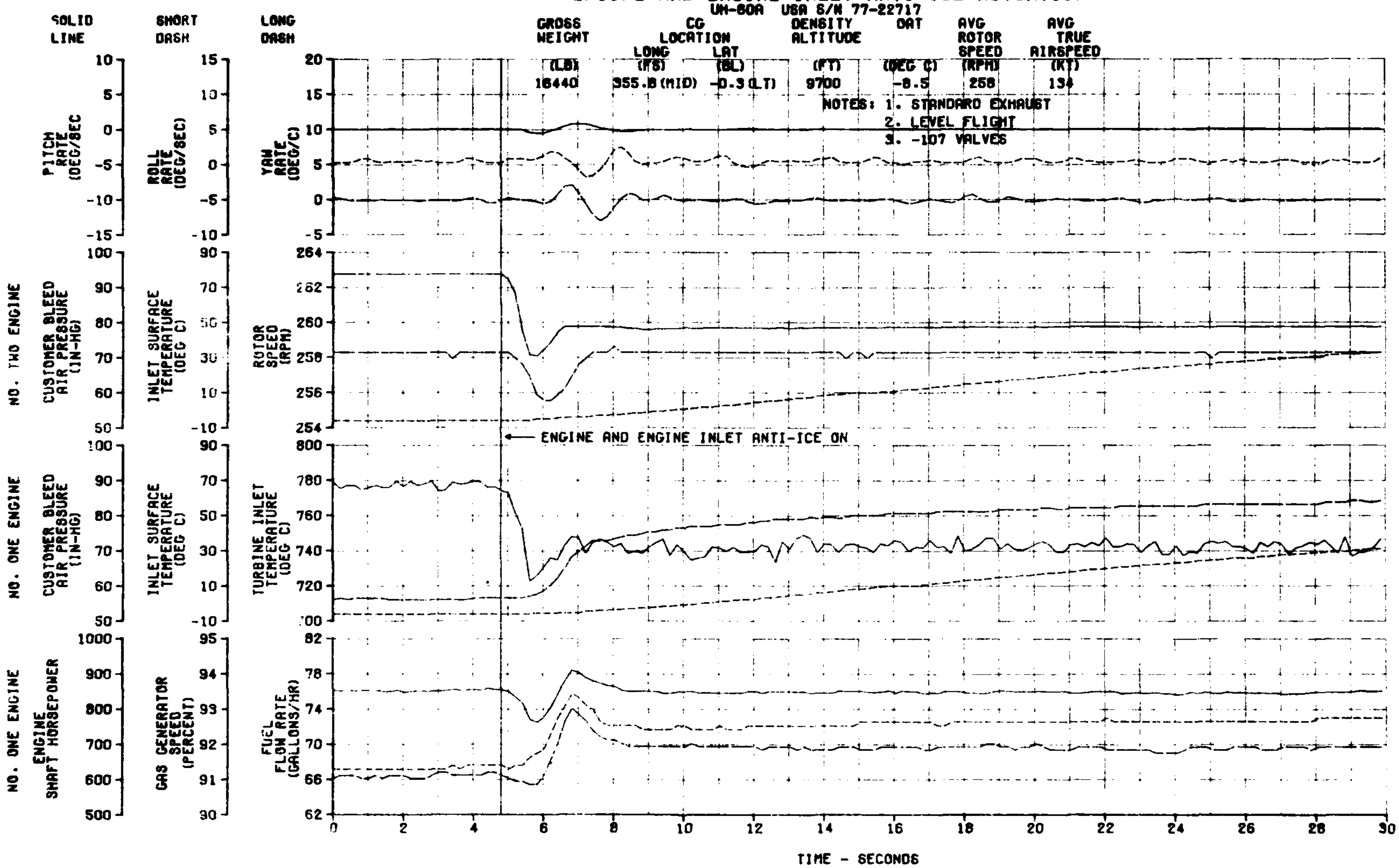
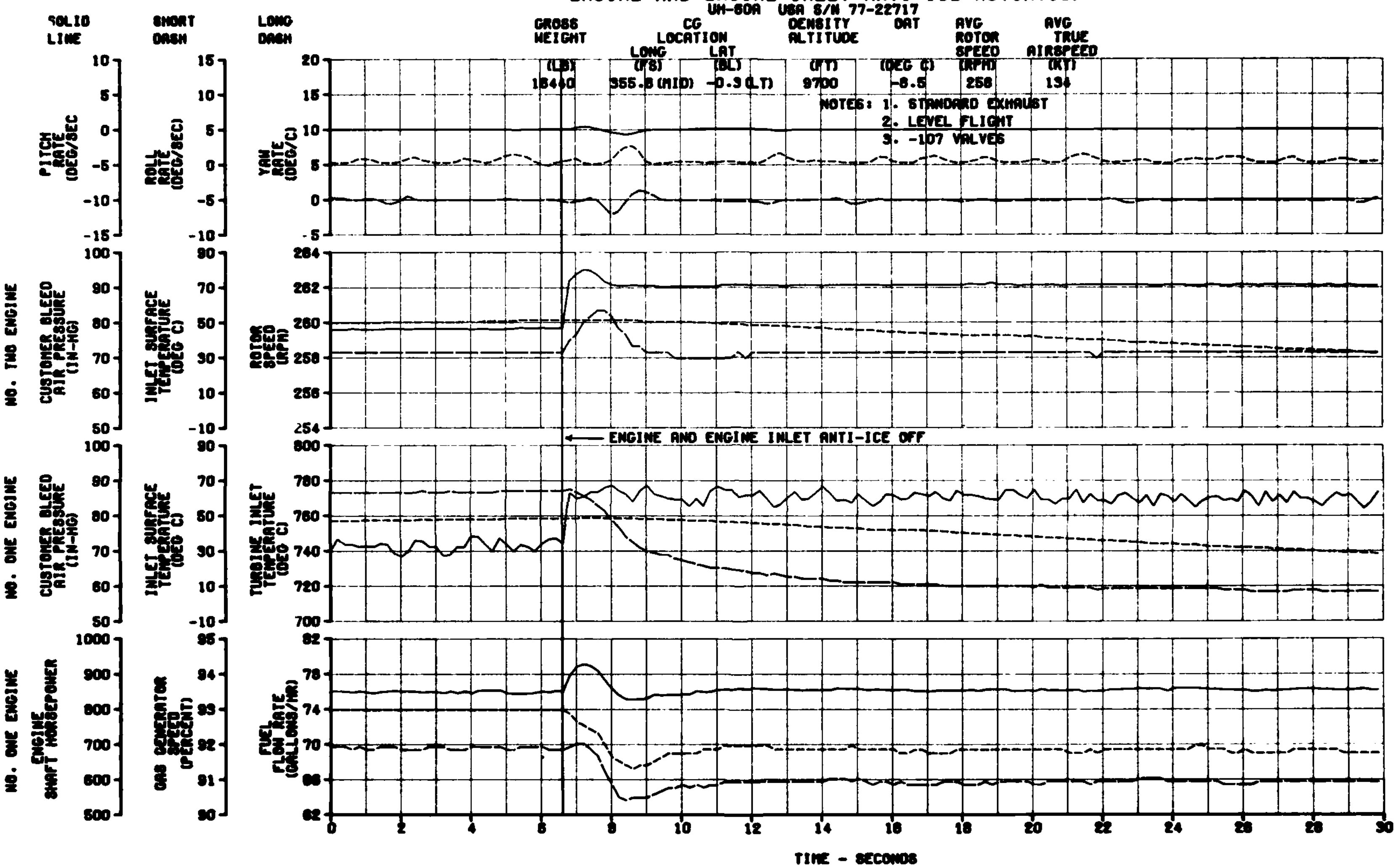


FIGURE 32

ENGINE AND ENGINE INLET ANTI-ICE ACTUATION

UH-60A USA S/N 77-22717

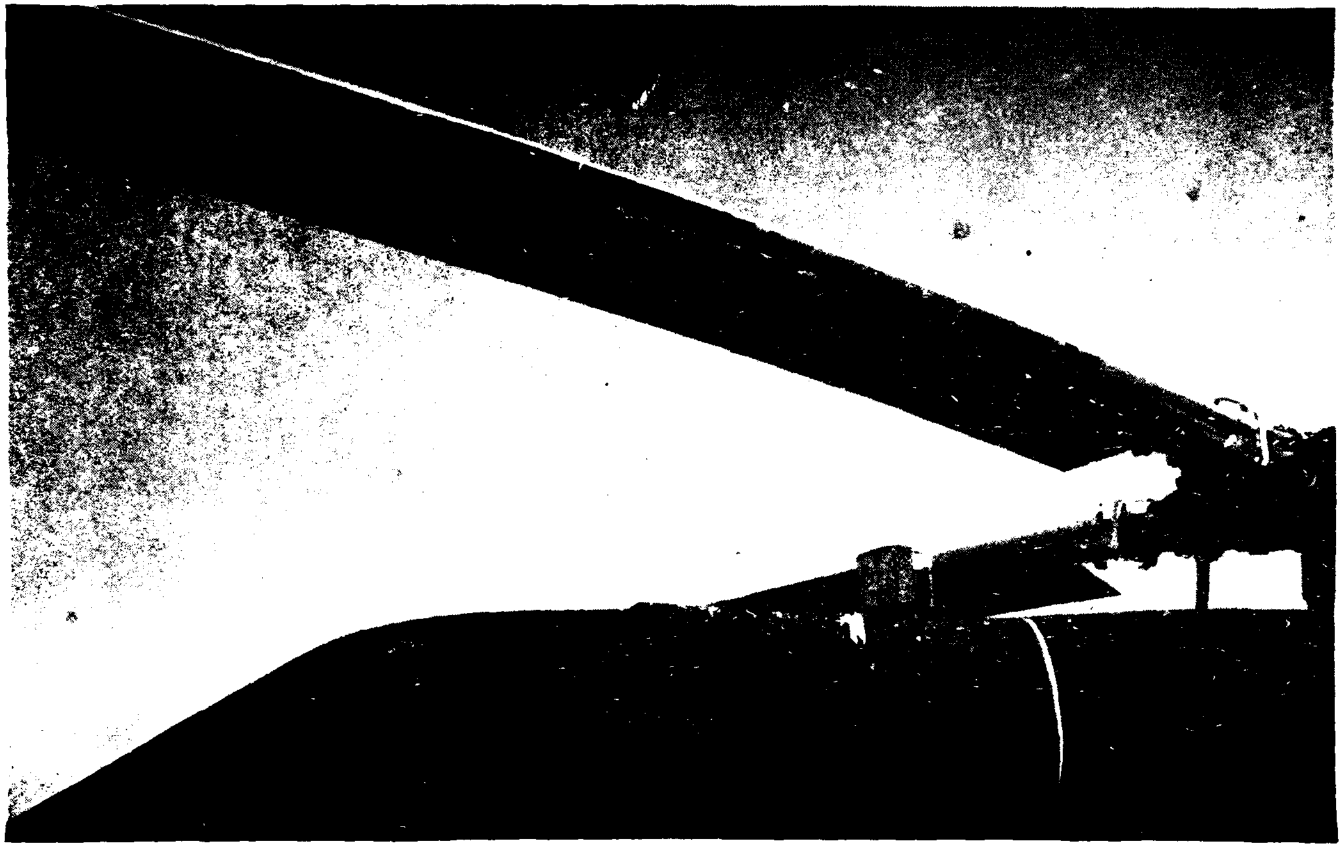


APPENDIX G. EQUIPMENT PERFORMANCE REPORTS

The following Equipment Performance Reports (EPR) SAV Form 1002, 7 April 1970 were submitted during the conduct of this evaluation.

EPR Number	Subject
79-19-01	Tail rotor gearbox inspection
79-19-02	Tail rotor gearbox inspection
79-19-03	Main rotor tip cap erosion shield debonding
79-19-04	Bifilar washer wear
79-19-05	Troop seat worn
79-19-06	Droop step icing
79-19-07	Anti-flapping restrainer icing
79-19-08	Windshield anti-icing wiring
79-19-09	Icing rate meter fail flag
79-19-10	Windshield anti-ice/ADF noise
79-19-11	Main rotor drip pan assembly drain capacity
79-91-12	Main rotor distributor failure
79-19-13	Fault monitor panel EMI
79-19-14	Engine fire extinguisher gauge reading
79-19-15	Tail rotor jumper assembly, bonding
79-19-16	IR suppressor standoff rivets
79-19-17	Droop stop icing
79-19-18	Windshield anti-ice control failure
79-19-19	Tail rotor slip ring assembly failure
79-19-20	Tail rotor slip ring brush block wear
79-19-21	Deice system controller failure

APPENDIX H. PHOTOGRAPHS

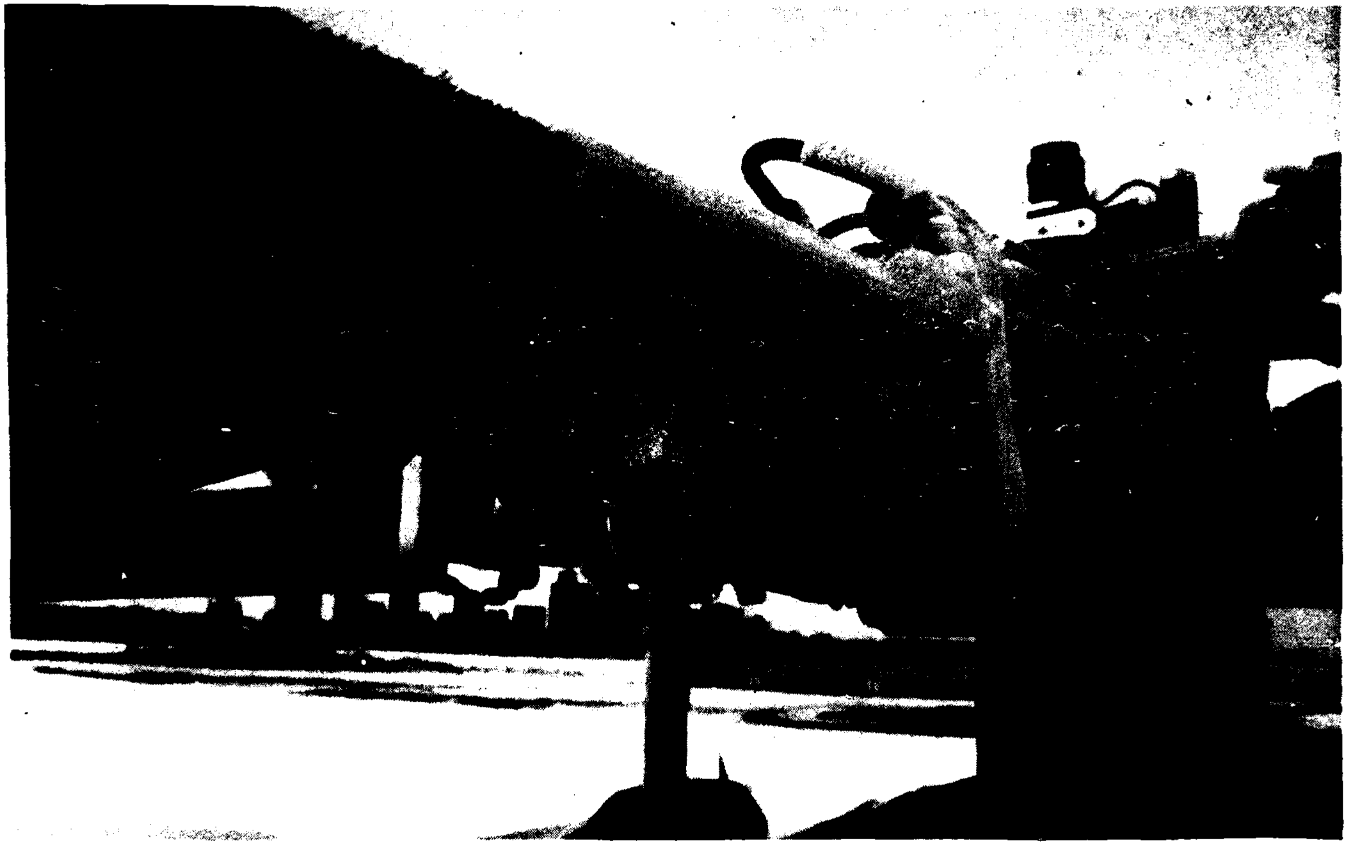


Conditions:	Environment - Artificial	Avg OAT - -21.5°C
	Configuration - IR	Avg LWC - 0.25°C, 0.50 gm/m^3
	Flight - 7	Time in Cloud - 45 minutes

Photo 1. Runback on Main Rotor Blade

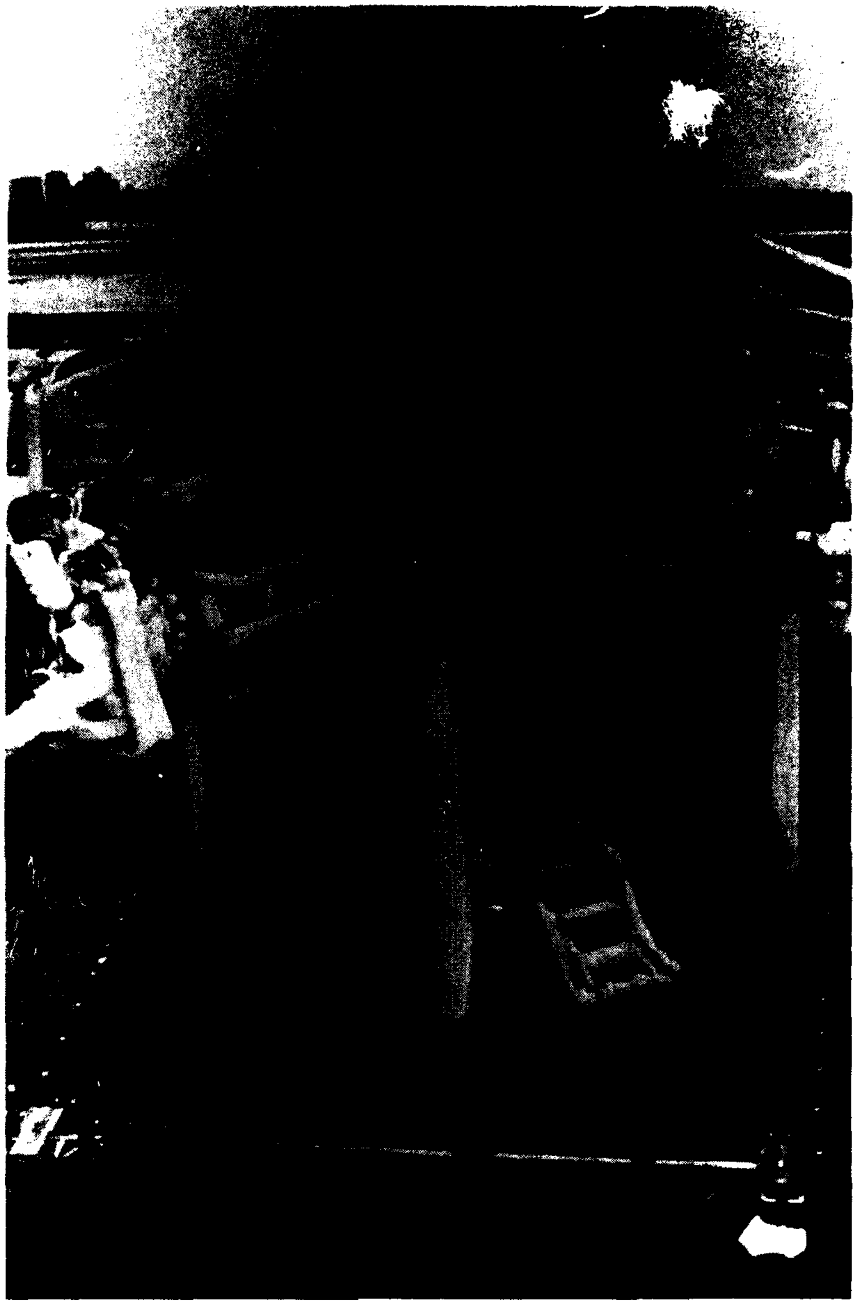
Conditions:	Environment - Natural	Avg OAT - -40 °C
	Configuration - Clean	Avg LWC - 0.32 gm/m^3
	Flight - 24	Time in Cloud - 95 minutes

Photo 2. Ice on Center Windshield



Conditions:	Environment - Artificial	Avg OAT - -20.0°C
	Configuration - IR	Avg LWC - 0.50, 0.75, 1.0 gm/m^3
	Flight - 11	Time in Cloud - 60 minutes

Photo 3. Unprotected Areas of Main Rotor Blade



Conditions: Environment - Natural Avg OAT - -12.0°C
Configuration - IR Avg LWC - 0.09 gm/m3

Conditions: Environment - Natural Avg OAT - -12.0°C
Configuration - IR Avg LWC - 0.09 gm/m^3
Flight - 9 Time in Cloud - 90 minutes

Photo 4. Unprotected Main Rotor Head

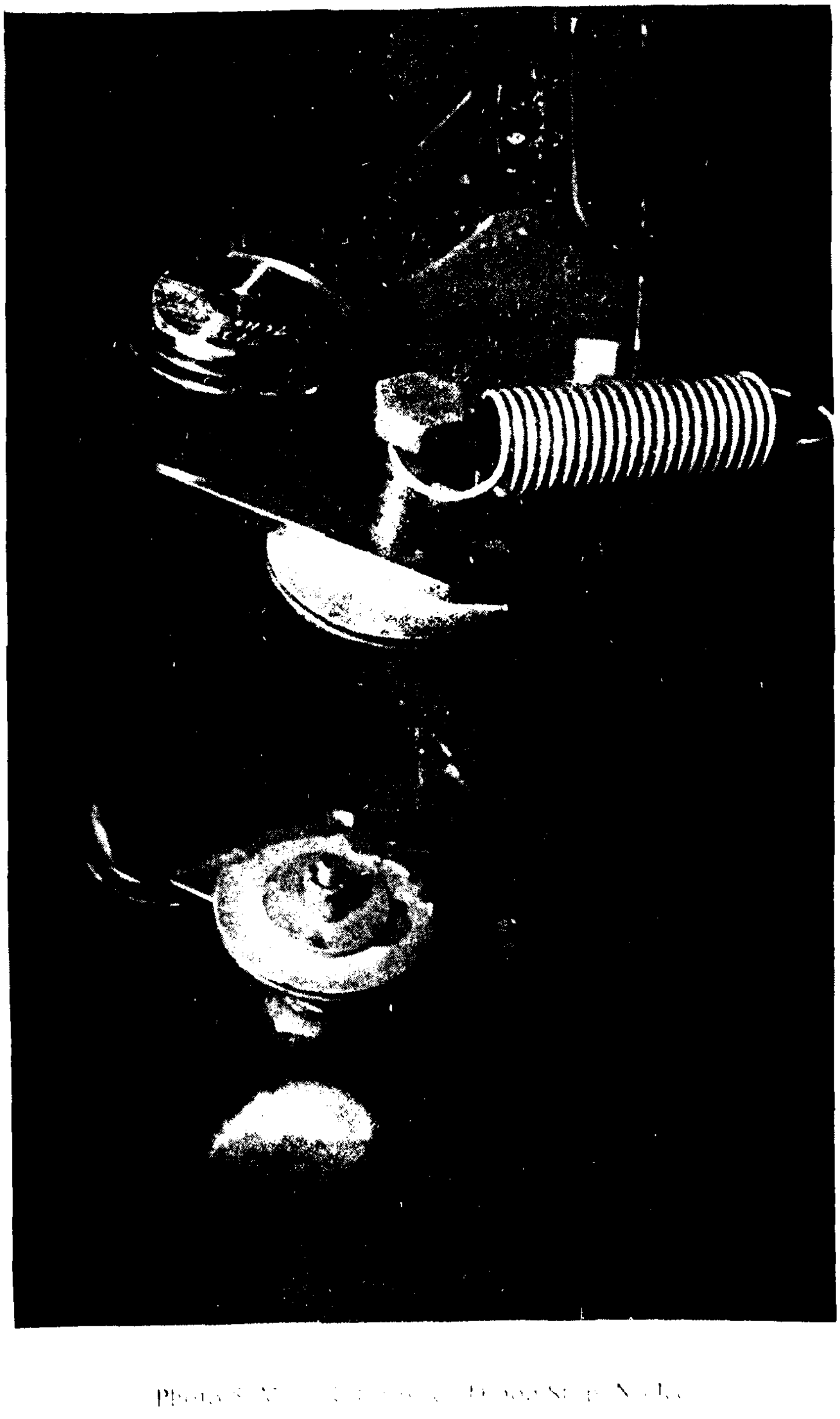
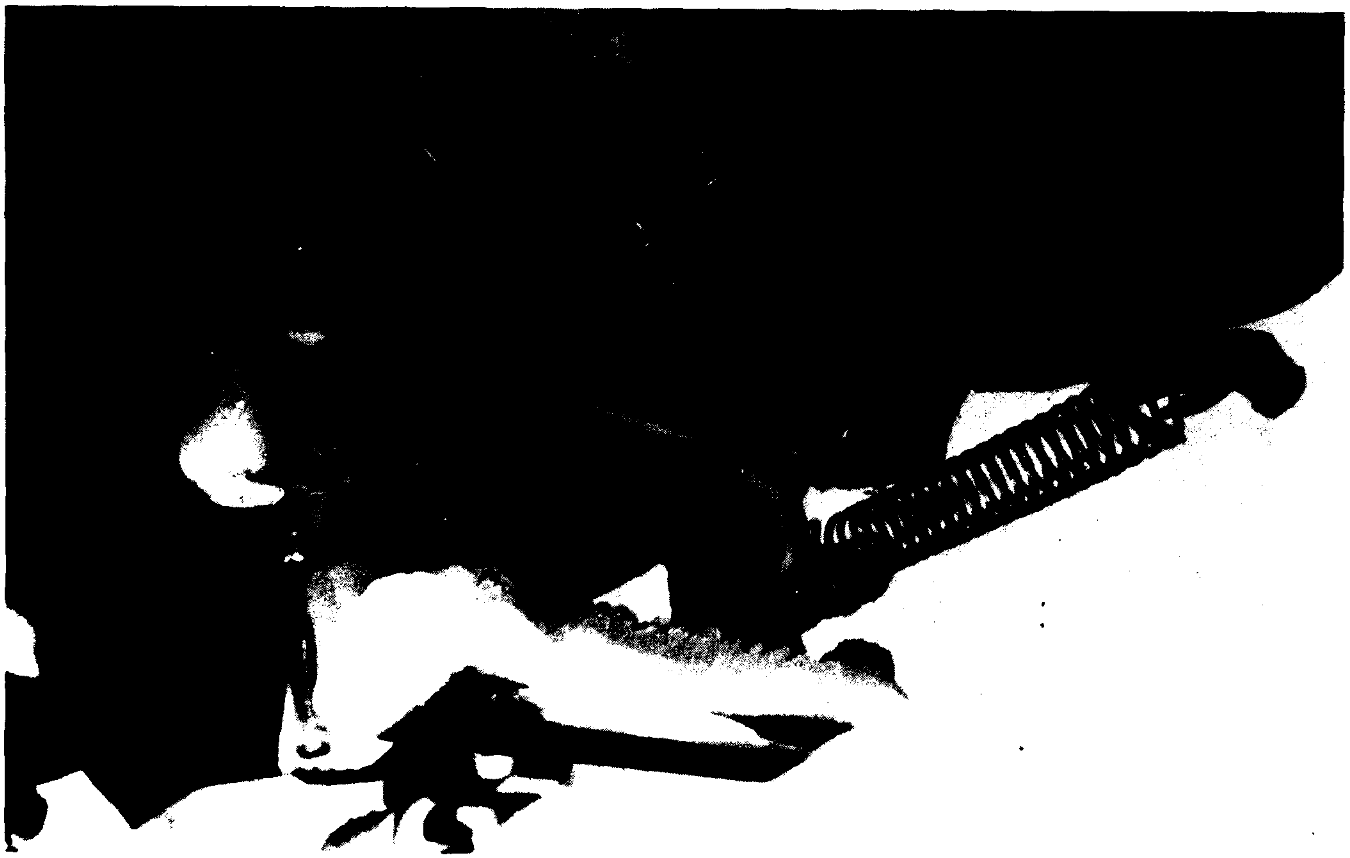


Photo [illegible]



Conditions:	Environment - Natural	Avg OAT - -12.0 °C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 6. Main Rotor Blade Droop Stop, with Ice

Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 7. Main Rotor Blade Droop with Stop Out

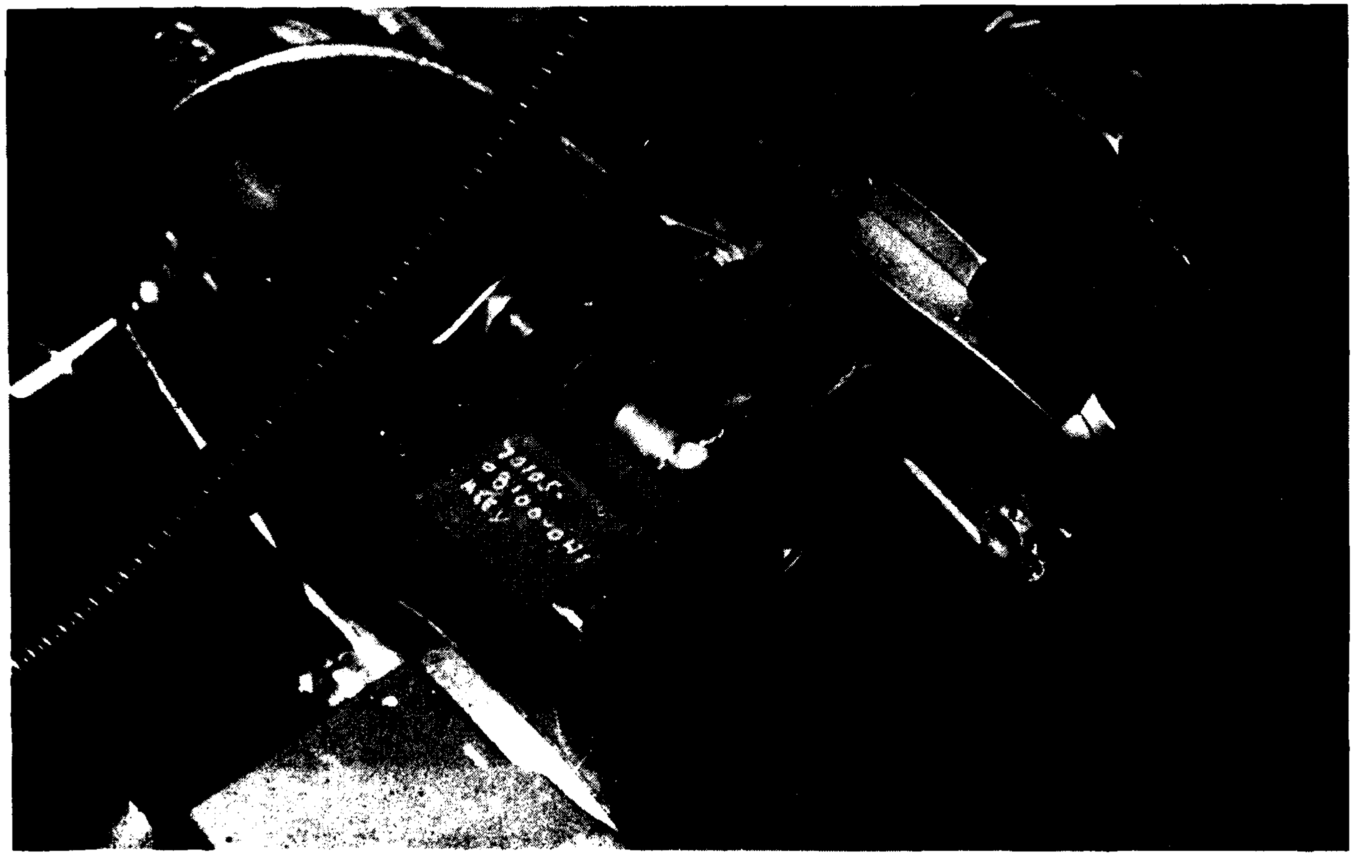
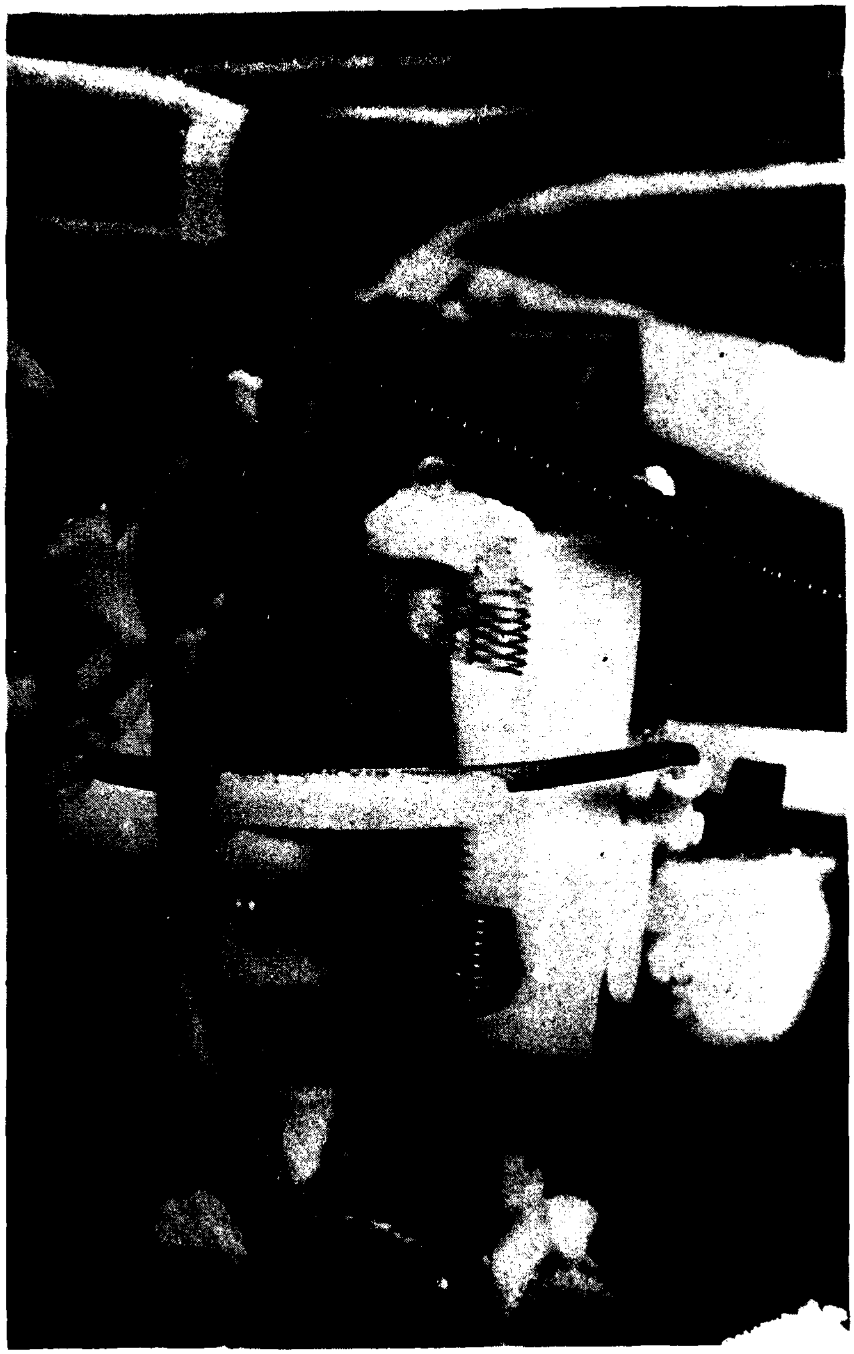
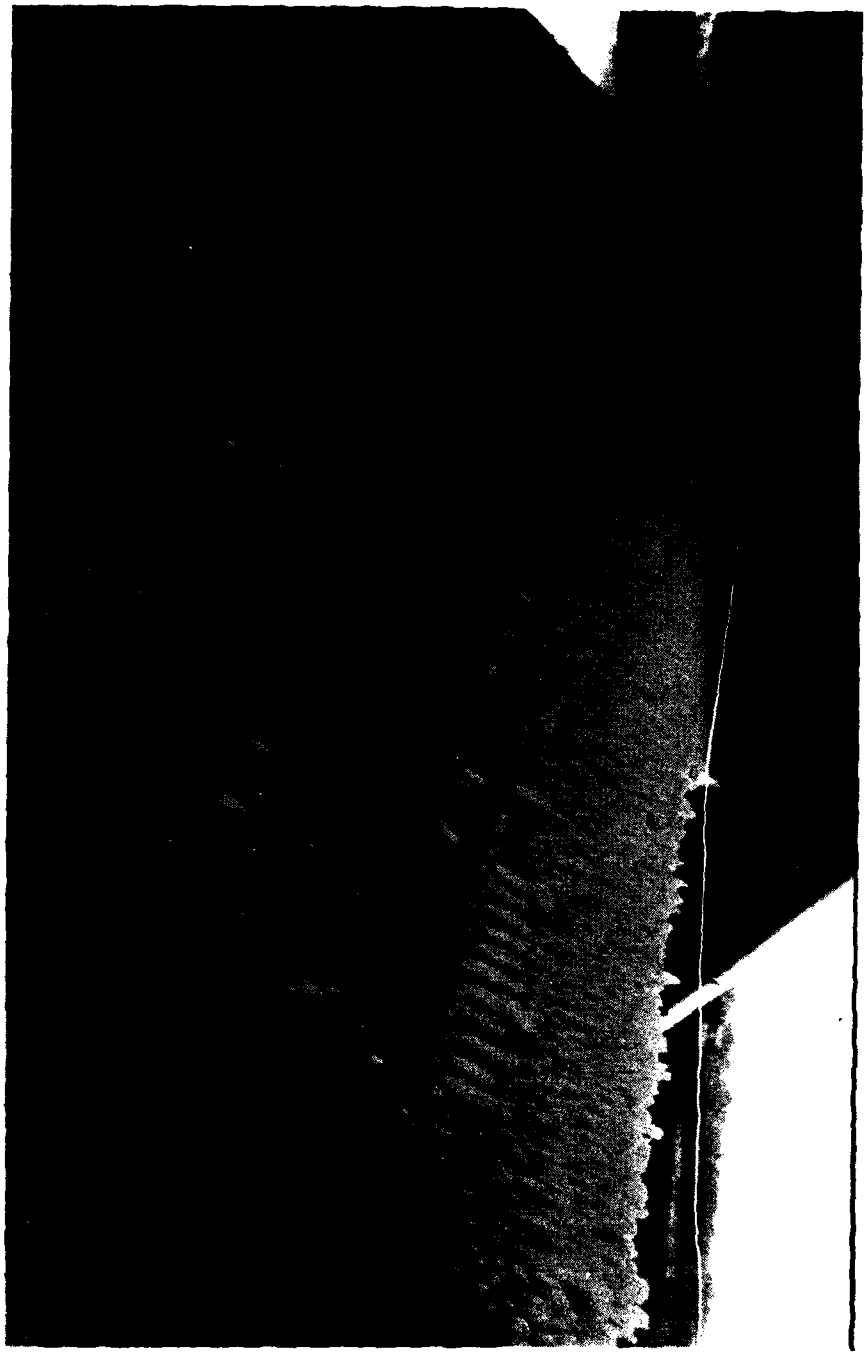


Photo 8. Anti-Flapping Restrainer, No Ice



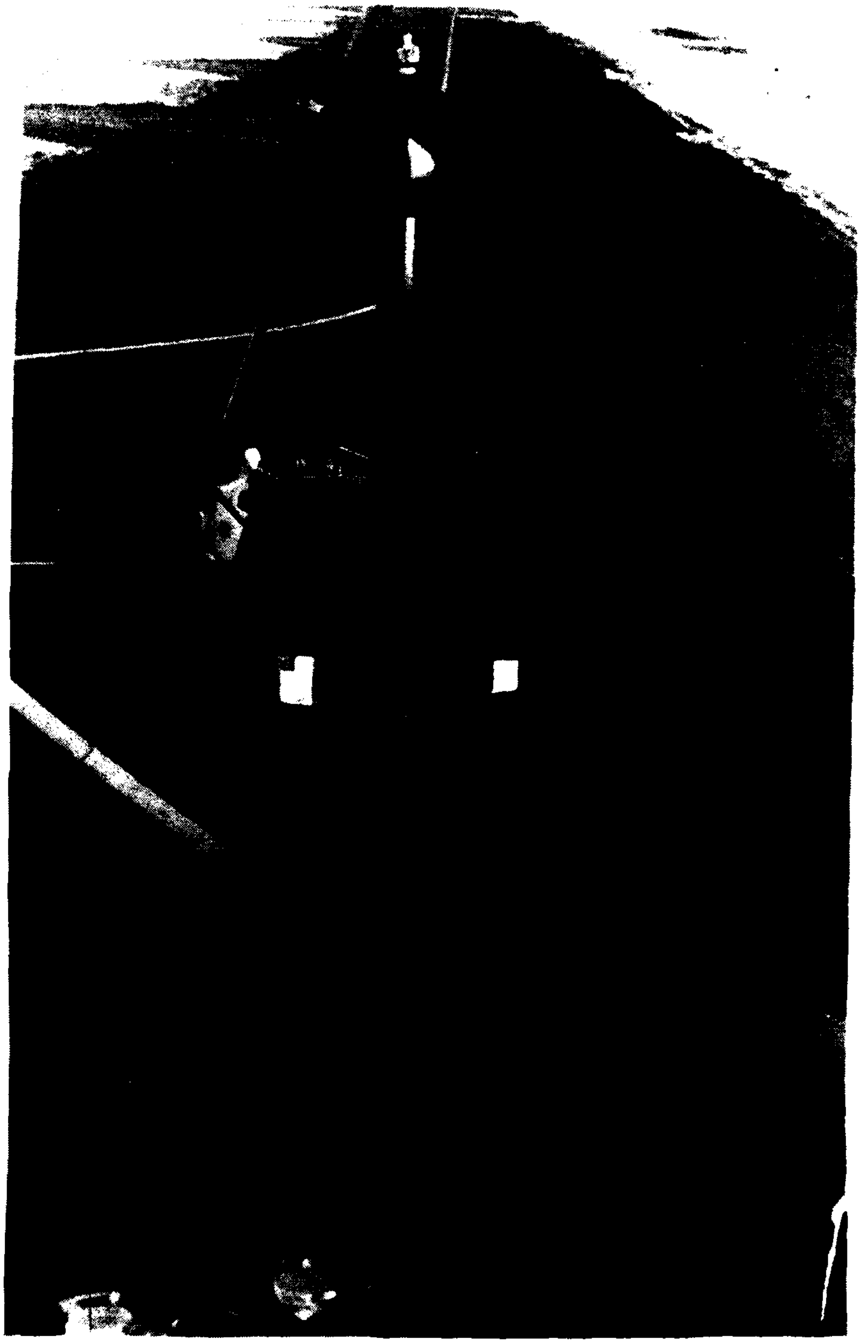
Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 9. Anti-Flapping Restrainer, with Ice



Conditions:	Environment - Artificial	Avg OAT - -20.0°C
	Configuration - IR	Avg LWC - 0.50, 0.75, 1.0 gm/m^3
	Flight - 11	Time in Cloud - 60 minutes

Photo 10. Stabilator Ice Accretion



Conditions:	Environment - Natural	Avg OAT - -5.5°C
	Configuration - Clean	Avg LWC - 0.05 gm/m^3
	Flight - 13	Time in Cloud - 90 minutes

Photo 11. Stabilator Ice Accretion

Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

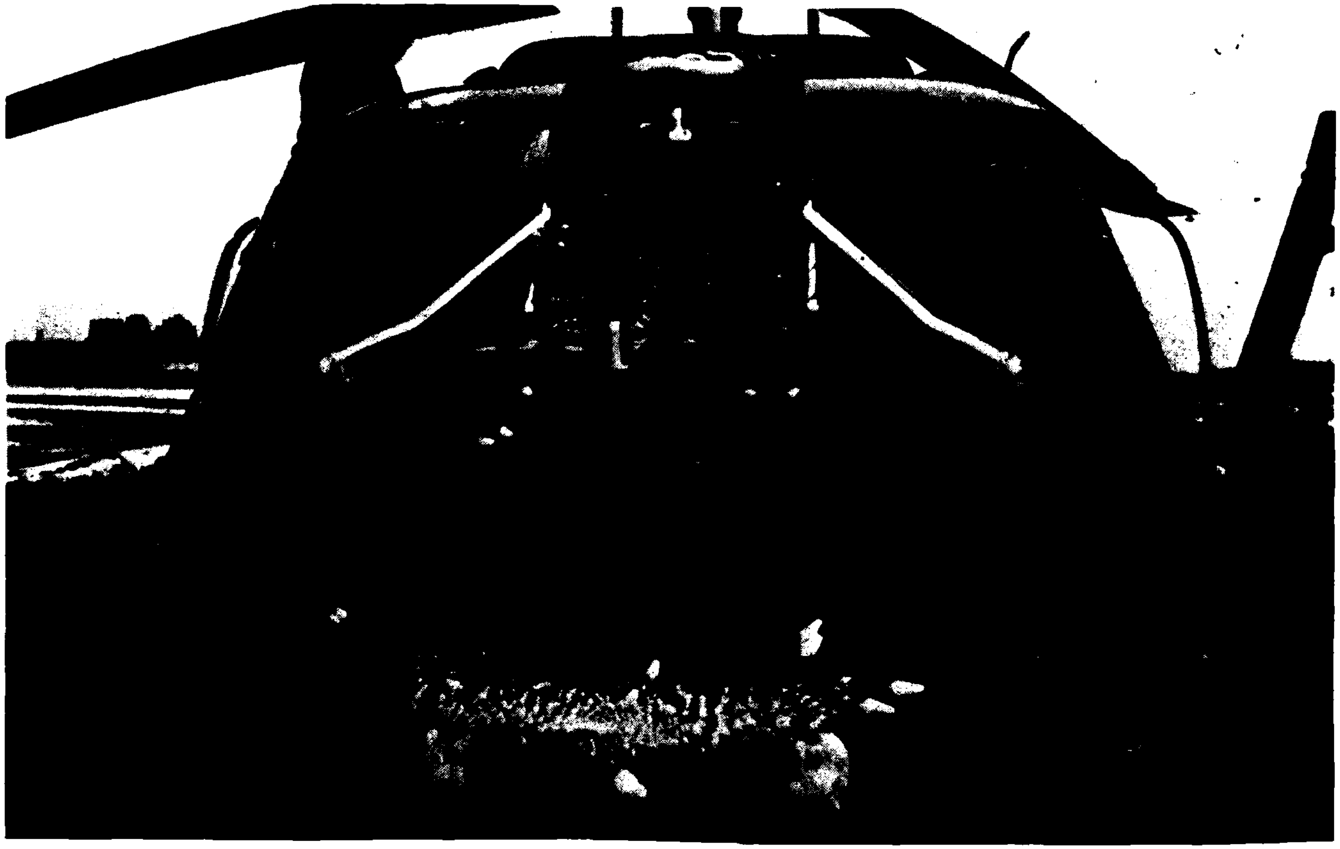
Photo 12. Airframe Ice Accretion

Conditions: Environment - Natural; Configuration - IR; Flight - 9; Avg OAT - -12.0°C; Avg LWC - 0.09 gm/m^3; Time in Cloud - 90 minutes

Photo 13. Cockpit Stop Ice Accretion

Conditions:	Environment - Natural	Avg OAT - -7.5°C
	Configuration - IR	Avg LWC - 0.24 gm/m^3
	Flight - 6	Time in Cloud - 65 minutes

Photo 14. Windshield Wiper Mechanism, with Ice

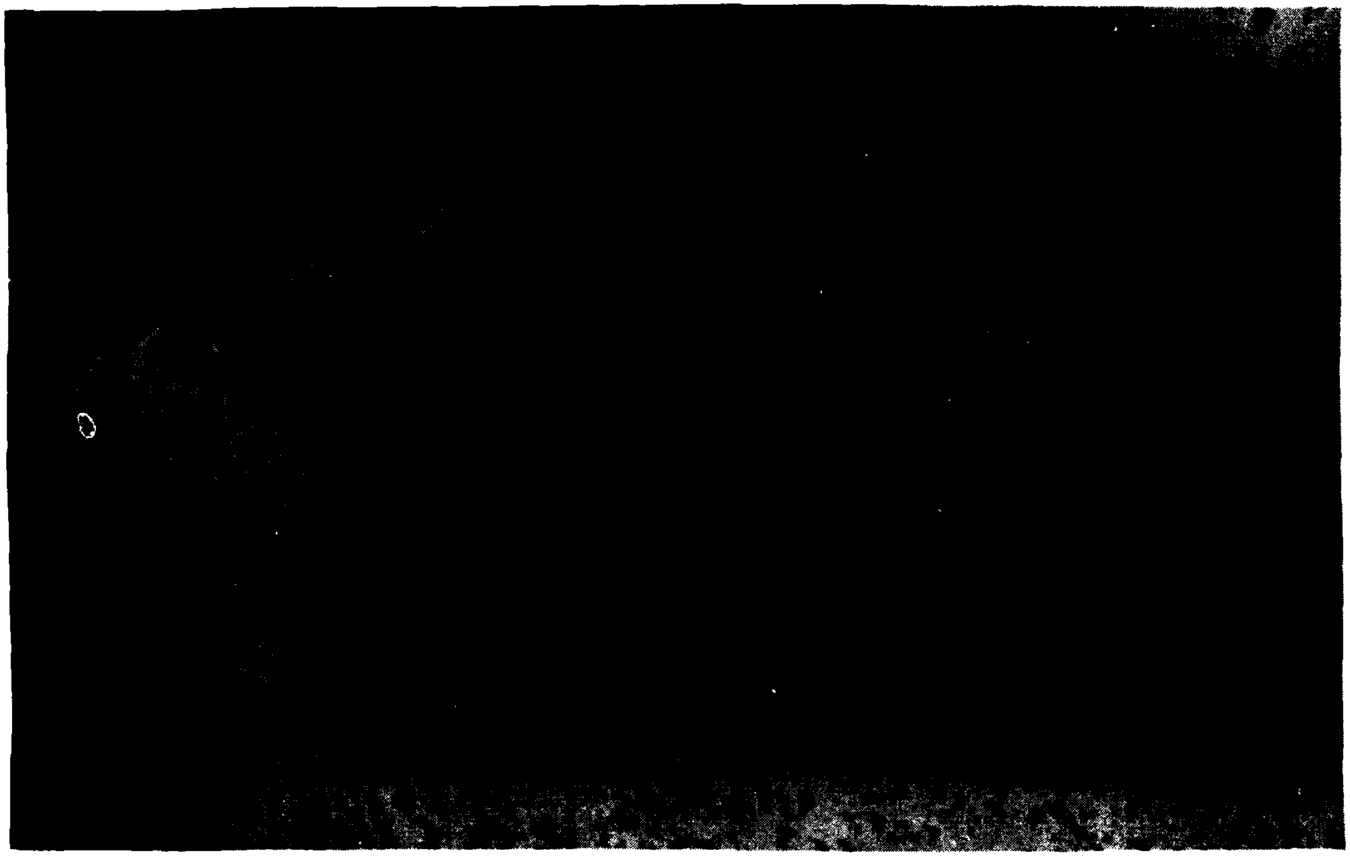


Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 15. Ice Accretion on Nose of Aircraft

Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 16. Deice System OAT Sensor, with Ice

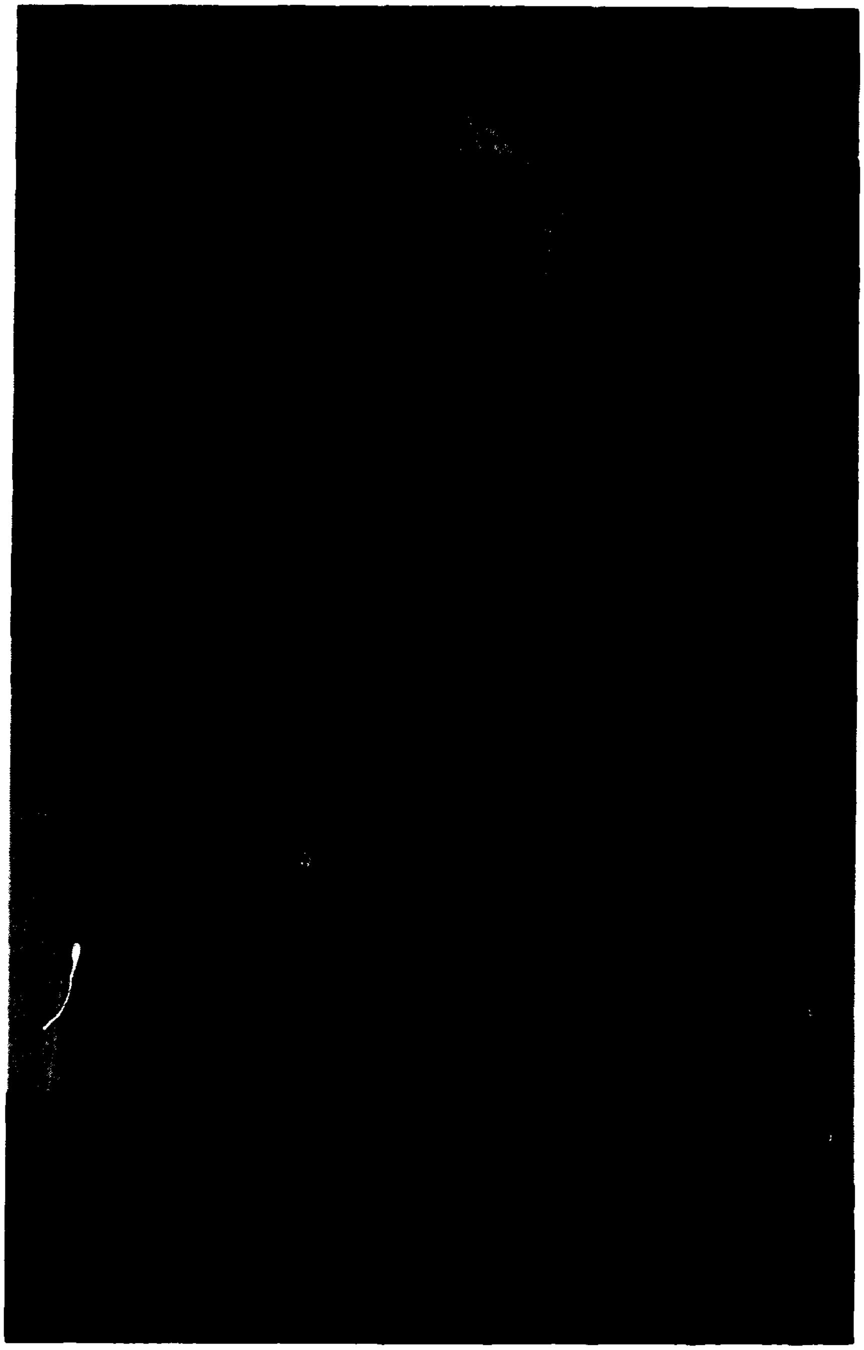


Conditions:	Environment - Natural	Avg OAT - -7.5°C
	Configuration - Clean	Avg LWC - 0.24 gm/m^3
	Flight - 27	Time in Cloud - 105 minutes

Photo 17. Ship OAT Senor, with Ice

Conditions:	Environment - Natural	Avg OAT - -7.0°C
	Configuration - Clean	Avg LWC - 0.07 gm/m^3
	Flight - 28	Time in Cloud - 120 minutes

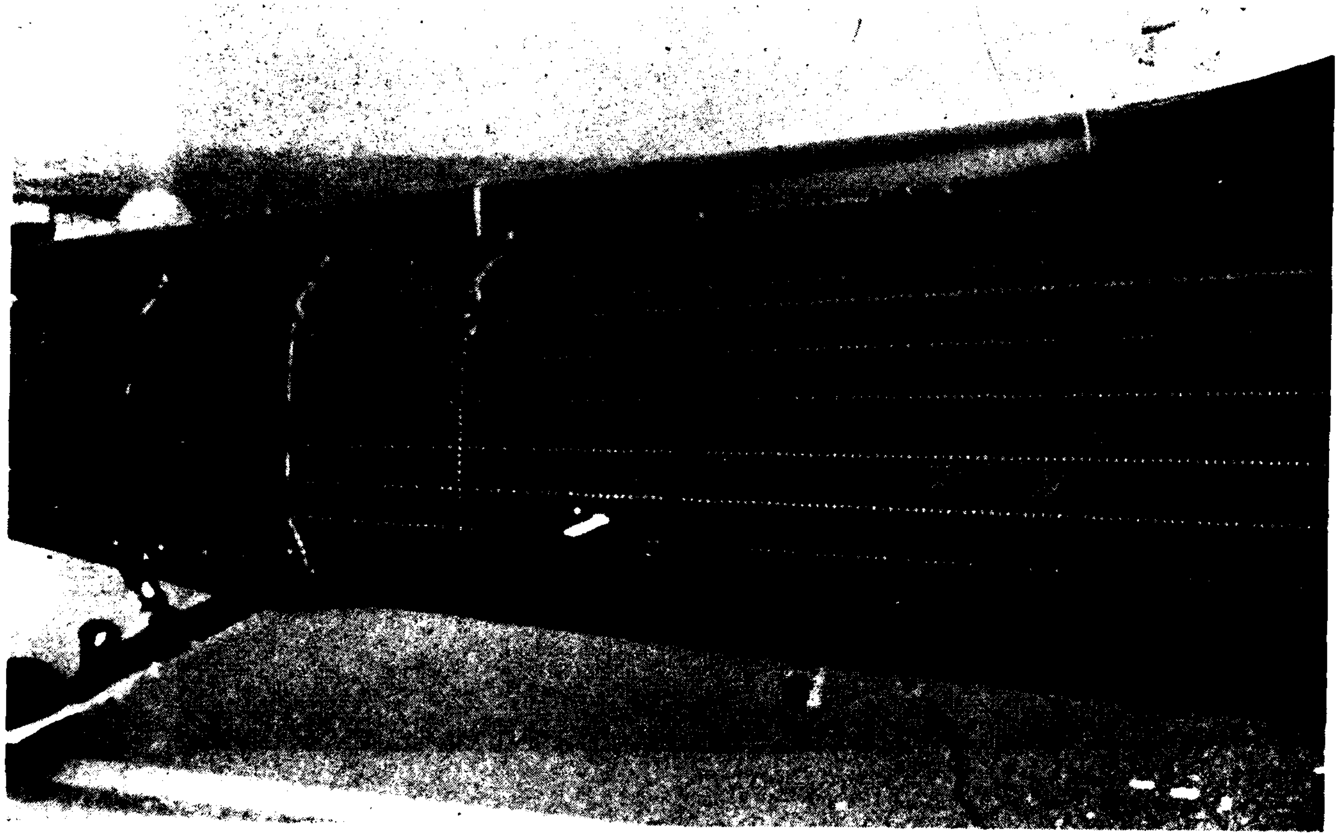
Photo 18. Cargo Hook, with Ice



Conditions: Environment - Artificial | Avg OAT - -20.0°C
Configuration - IR | Avg LWC - 0.50, 0.75, 1.0 gm/m^3
Flight - 11 | Time in Cloud - 60 minutes

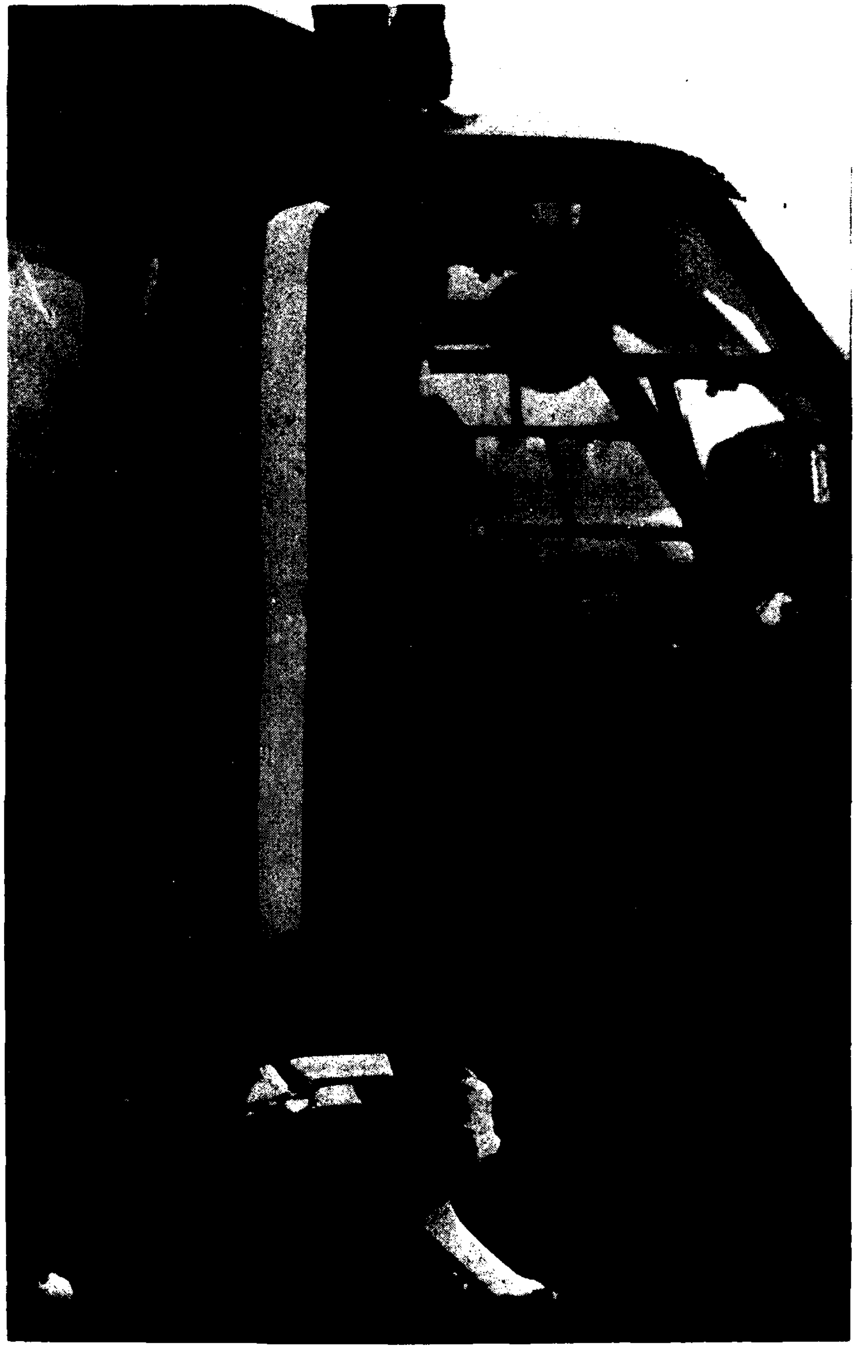
Conditions:	Environment - Artificial	Avg OAT - -20.0°C
	Configuration - IR	Avg LWC - 0.50, 0.75, 1.0 gm/m^3
	Flight - 11	Time in Cloud - 60 minutes

Photo 19. Tail Rotor Pylon, with Ice



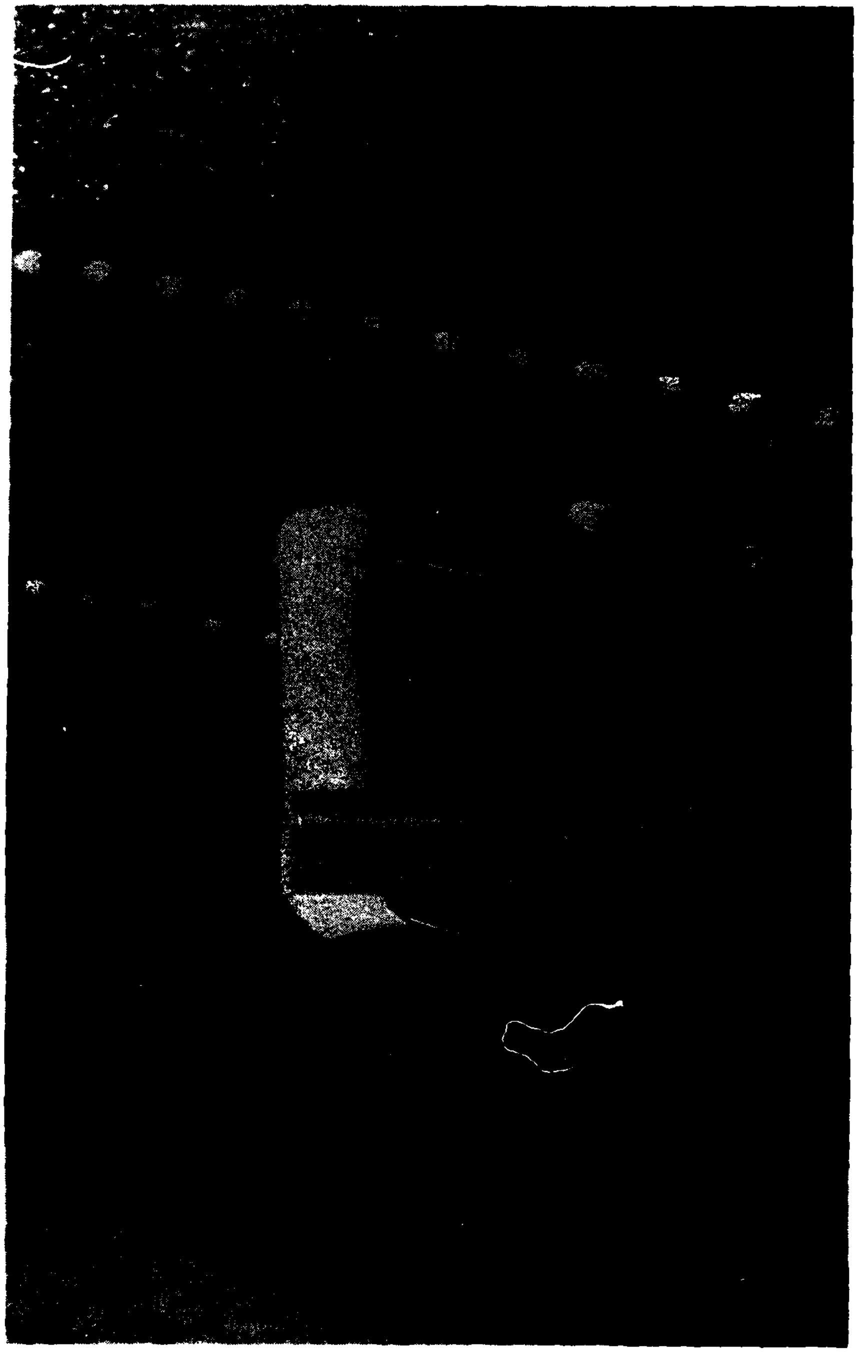
Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 20. Ice Accretion on Tailboom



Conditions:	Environment - Natural	Avg OAT - -11.0°C
	Configuration - Clean	Avg LWC - 0.06 gm/m^3
	Flight -19	Tme in Cloud - 105 minutes

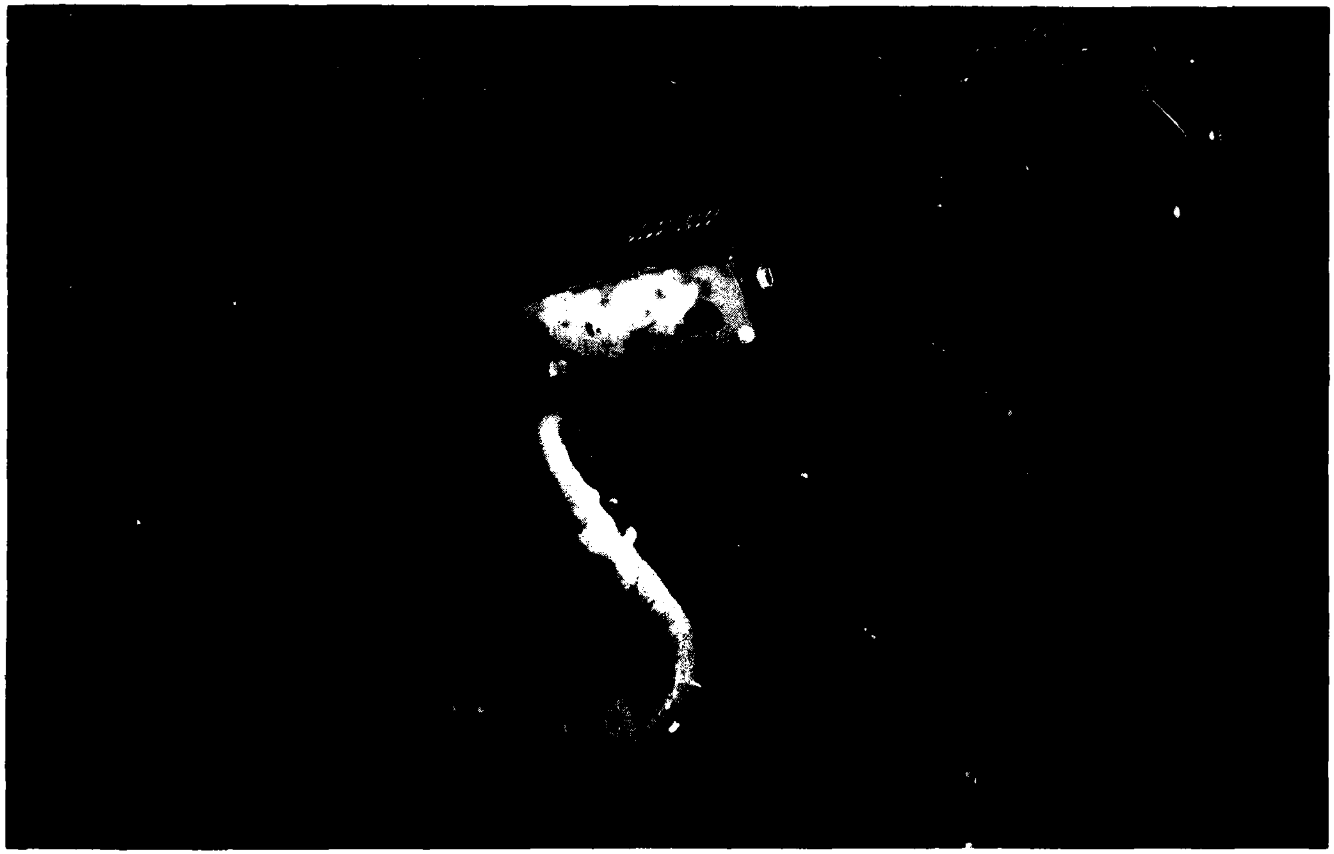
Photo 21. FM Antenna, Ice Accretion



Conditions:

Environment - Natural	Avg OAT - -12.0°C
Configuration - IR	Avg LWC - 0.09 gm/m^3
Flight - 9	Time in Cloud - 90 minutes

Photo 22. VOR Antennas, with Ice

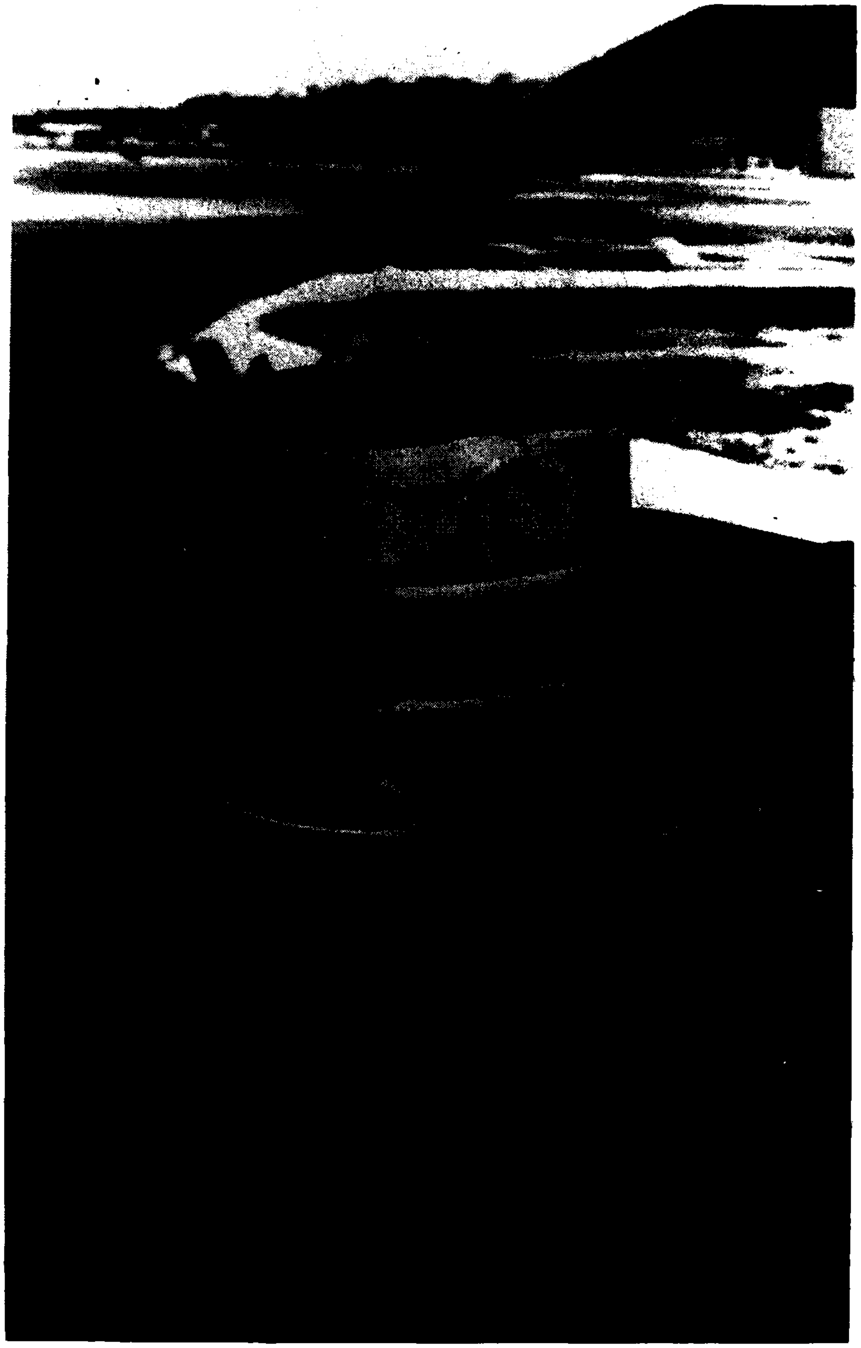


Conditions:	Environment - Natural	Avg OAT - 11.0°C
	Configuration - Clean	Avg LWC - 0.06 gm/m^3
	Flight - 19	Time in Cloud - 105 minutes

Photo 23. M-130 Chaff Dispenser Ice Accerction

Conditions:	*Environment* - *Artificial*	Avg OAT - -20.0°C
	Configuration - IR	Avg LWC - 0.50, 0.75, 1.0 gm/m^3
	Flight - 11	Time in Cloud - 60 minutes

Photo 24. Artificial Ice Accretion on ALQ-144 IR Countermeasures Device



Conditions:	Environment - Natural	Avg OAT - -12.0°C
	Configuration - IR	Avg LWC - 0.09 gm/m^3
	Flight - 9	Time in Cloud - 90 minutes

Photo 25. Natural Ice Accretion on ALQ-144 IR Countermeasures Device

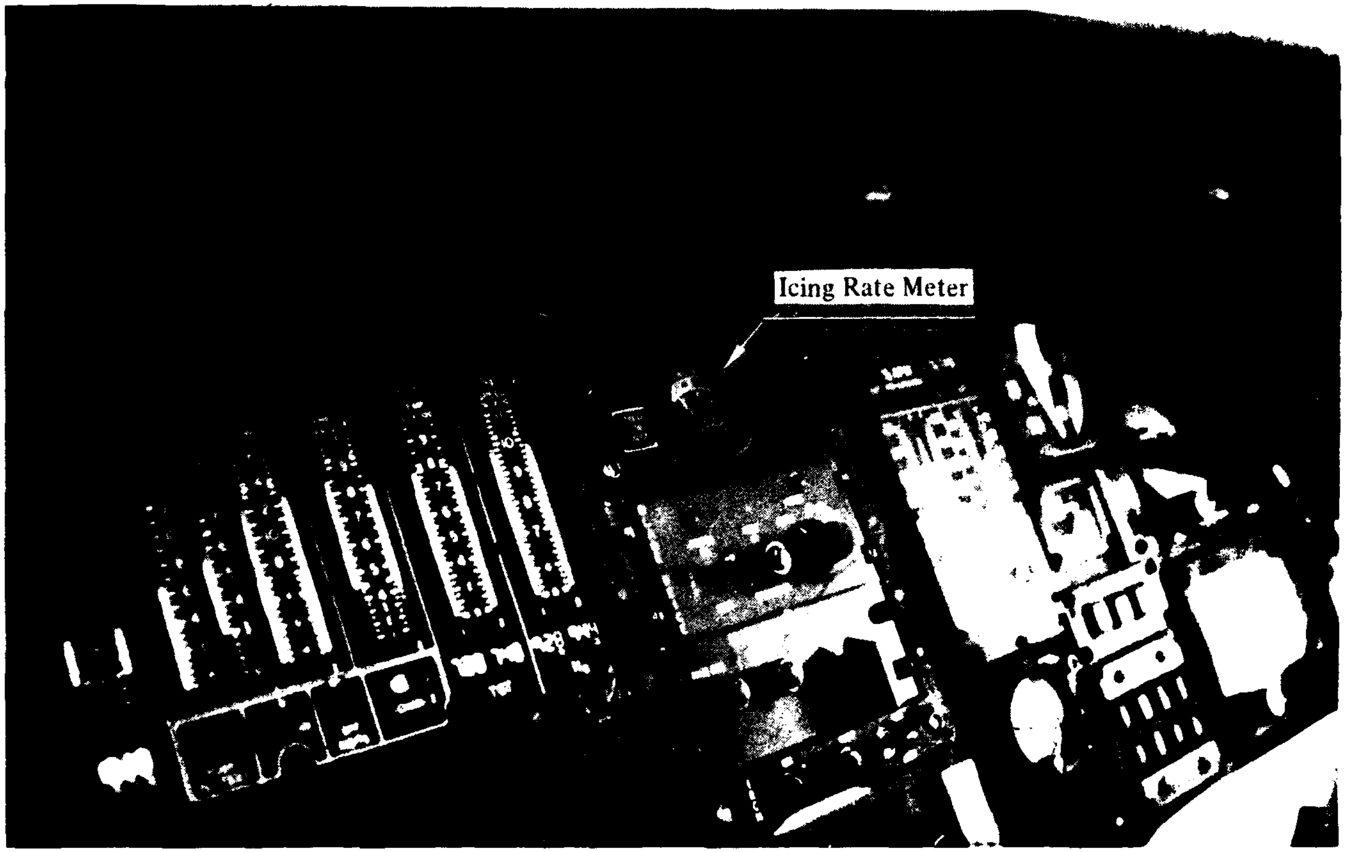


Photo 26. Icing Rate Meter Location

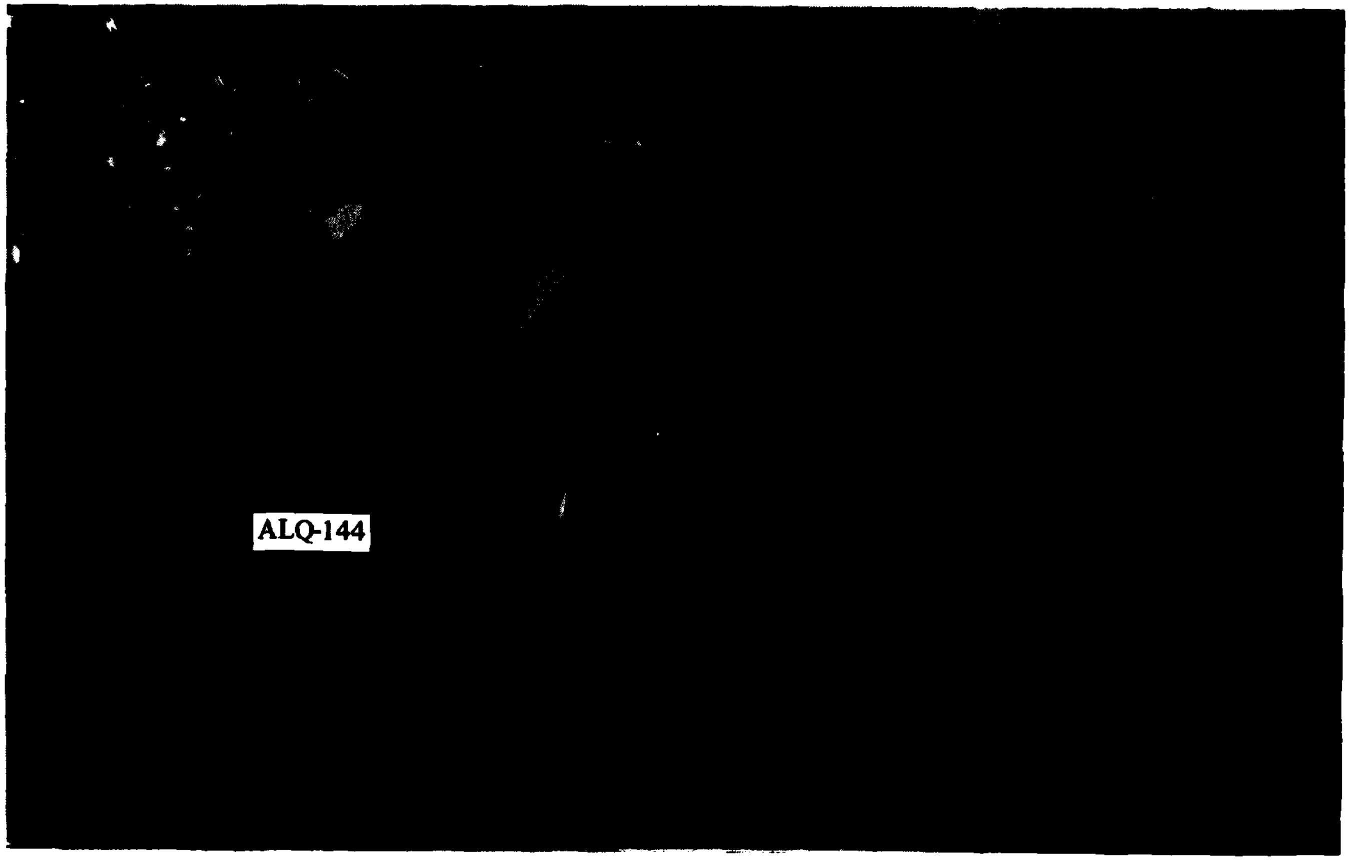


Photo 27. Main Rotor Blade Interference with ALQ-144

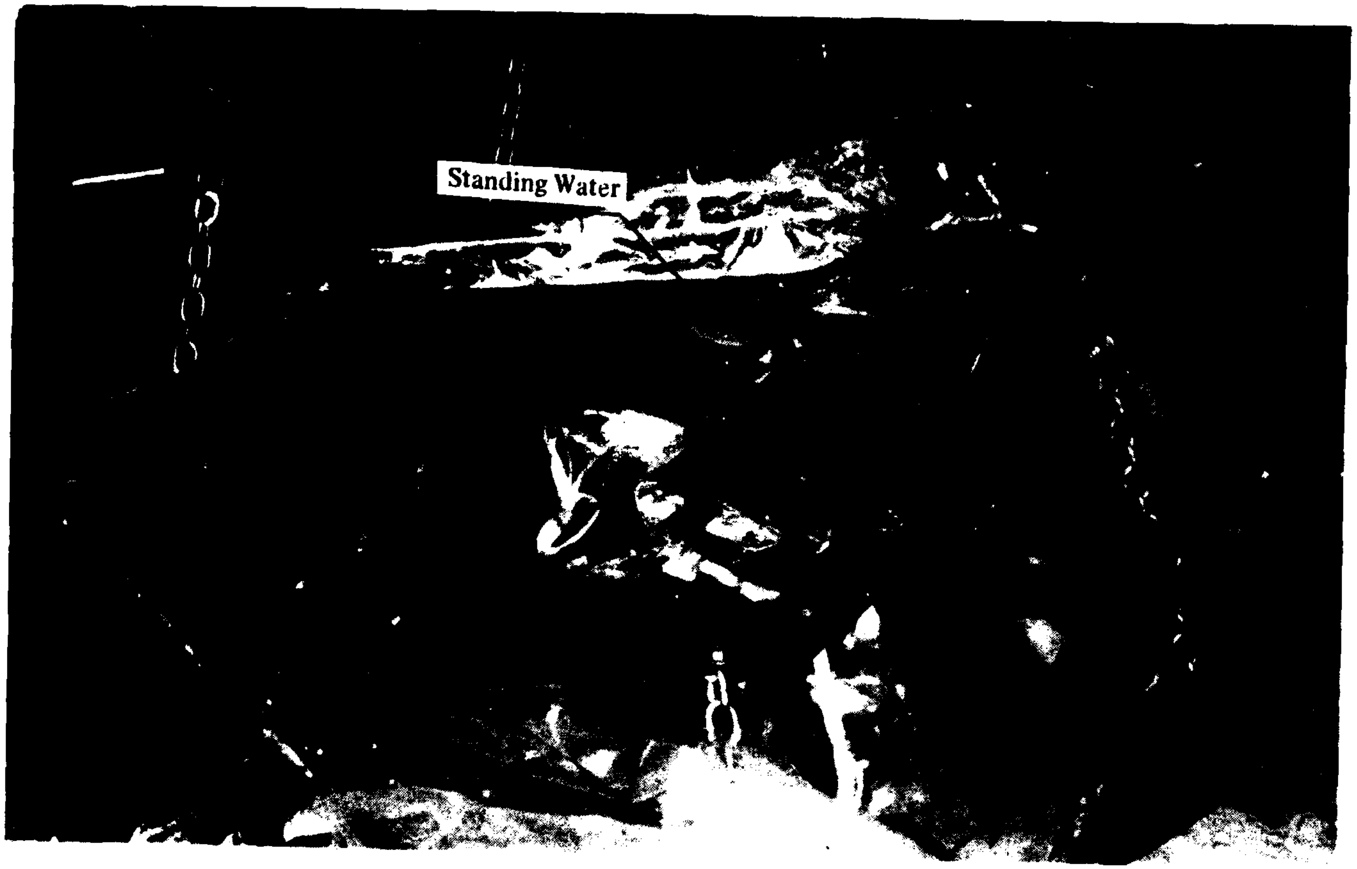


Photo 28. Instrumentation Package with Water Cover

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